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Studies and Research Projects

REPORT **R-715**

A Review of Cancer among Shipyard Workers

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A Review of Cancer among Shipyard Workers

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EXECUTIVE SUMMARY

The current review was initiated to better understand the cancer risk associated with working in shipyards. Our goal in assessing the causes of cancer among these workers was to guide those responsible for determining compensation for occupationally-related disease. With this objective all currently available literature, relevant to assessment of cancer risk among shipyard workers has been reviewed. A review of the main exposures to known carcinogens in shipyards gives one starting point for the review by identifying the potential contribution of known hazards. The review concentrates on epidemiological studies of shipyard workers aimed at identifying reproducible patterns of cancer incidence and mortality with an objective of understanding any associations with known hazards. The review also takes account of the classification of several shipyard occupations (e.g. Painter) not necessarily associated with excess risk among shipyard workers but with occupational exposure classified as carcinogenic by international bodies such as the International Agency for Research on Cancer (IARC), without specifying the causative agent.

The review considers today's cancer risks, which, due to a latency period of 5 to 40 years between first exposure and cancer diagnosis, are primarily based on exposures that occurred between 1930 and 1990. It is therefore important to note that the exposures and thus the risks that we evaluate may reflect circumstances no longer relevant to the current generation of shipyard workers, where stricter procedures are in place to minimise harmful exposures. For this reason any conclusion concerning cancer rates related to occupation may not be relevant to groups more recently employed, even though the hazards may still be present.

A range of cancer hazards relevant to shipyards have been considered and those showing an association with shipyard exposures were reviewed as a potential source of cancer risk for shipyard workers. All available data on cancer in shipyard workers are taken into account in concluding on the importance of those factors associated with a risk of cancer. From this review those cancers for which there is evidence of an association with occupational exposure in shipyards are summarised in the following table.

A refined quantitative evaluation of risks is not possible due to lack of data on actual exposures, employment history and potentially confounding factors such as smoking habit. Nonetheless the

review includes a crude ranking of the importance of each risk identified. Many of the studies conducted in shipyard workers are, for various reasons, unlikely to detect all excess cancer risks.

Occupational exposure	Cancer type	IARC classification	Evidence in shipyards	Occupations exposed in shipyards	Relevant cancer risk for shipyard workers ?
Asbestos	Lung, Larynx, mesothelioma	1	+	All workers	++
Ionizing Radiation	Leukaemia	1	+	Nuclear shipbuilding, Industrial radiographers	+
Painting	Bladder, Lung, Mesothelioma	1	-	Painters	+
Quartz	Lung	1	-	Sandblasters, by-standers	+
Benzene	Leukaemia	1	-	Painters	±
Metal-working fluids	Skin	1	-	Sheet-metal workers, machinists,	±
UV radiation	Skin	1	-	Welders, Sheet-metal workers	±
UV radiation	Ocular melanoma	1	-	Welders	+
Welding and flame cutting	Lung	2B	±	Welders, Sheet-metal workers	±
Wood dust	Nasopharynx, Nasal adenocarcinoma	1	+	Wood workers	+

The review concludes from epidemiologic studies of shipyard workers and other occupational groups that the main source of excess cancer risk among shipyard workers is asbestos exposure. This results in elevated rates of mesothelioma and cancer of lung and larynx for all shipyard workers. The highest levels of exposure to asbestos, and thus the highest cancer risk, occurred in shipyards before the mid-1970s.

There are some additional or competing risks for lung cancer for those shipyard workers employed as welders and painters. Due to lack of available data on relevant exposures the role of asbestos and smoking has not been fully resolved for those groups, however the evidence for some excess of cancer is consistently present in the studies reviewed. A specific risk of oro-nasal and naso-pharyngeal cancer exists for wood-workers in all industries and shipyards would not be

expected to be an exception. The risk has been demonstrated for shipyard workers in one study but lack of data on exposure makes any quantification of risk impossible. Similarly, metal workers (machinists) have an acknowledged risk of skin cancer, derived from exposure to some metal-working fluids, however the degree to which these exposures are relevant to shipyards is unknown. Ocular melanoma has been demonstrated to be related to UVR exposure in welders and thus although no incidence was detected in all the studies of shipyard workers it nevertheless represents an occupational risk for welders working in shipyards. A specific additional risk of leukaemia, proportionate to the level of exposure, may be present for those working with ionizing radiation in building and repairing nuclear-powered ships or working as industrial radiographers.

In the original plan of the review 15 occupational categories were identified and the following table summarises the likely cancer risks for each of those, plus other occupations identified during the review process. Where no specific risks were identified for a particular occupation the general risks of shipyard working are relevant. Mineral oil exposure of greasers, engine fitters, maintenance mechanics and some sheet-metal workers may carry an added risk of skin cancer and this is noted below, although no excess of such cancer was seen among shipyard workers.

Occupation	Main cancer risk
Burner	Lung, Larynx, Mesothelioma
Crane Operator	Lung, Larynx, Mesothelioma
Electrician	Lung, Larynx, Mesothelioma
Engine Fitter	Lung, Larynx, Mesothelioma, skin
Greaser	Lung, Larynx, Mesothelioma, Skin
Industrial radiographer	Lung, Larynx, Mesothelioma, Leukaemia
Joiner/Carpenter/Wood-worker	Lung, Larynx, Mesothelioma, Nasopharynx, Nasal adenocarcinoma
Labourer	Lung, Larynx, Mesothelioma
Lagger	Lung, Larynx, Mesothelioma
Maintenance Mechanics	Lung, Larynx, Mesothelioma, skin
Nuclear shipyard workers	Lung, Larynx, Mesothelioma, Leukaemia
Oiler	Lung, Larynx, Mesothelioma
Painter	Lung, Larynx, Mesothelioma, Bladder,Leukaemia
Pipefitter	Lung, Larynx, Mesothelioma
Rigger	Lung, Larynx, Mesothelioma
Sheet Metal Worker	Lung, Larynx, Mesothelioma, skin
Steel Worker	Lung, Larynx, Mesothelioma
Welder	Lung, Larynx, Mesothelioma, Skin, Ocular Melanoma

For all of the cancers described above the risk tends to increase with duration of employment and in many cases the risk is higher amongst those who were working in shipyards before 1980 when industrial hygiene practices were less stringent. The lag period between exposure and cancer diagnosis varies according to cancer type between 5 and 40 years.

CONTENTS

1. GENERAL INTRODUCTION

The current review was initiated to obtain a better understanding of the cancer risk associated with working in shipyards as a potential assistance to those responsible for deciding on compensation for occupationally-related disease. With this objective all currently available literature, relevant to assessment of cancer risk from working in shipyards has been reviewed. The main exposures to known carcinogens present in shipyards gives a starting point for the review by identifying some potential hazards. The review concentrates on epidemiological studies of shipyard workers aimed at identifying unusual patterns of cancer and specific review of any data relevant to understanding any associations with known hazards which may be present in the available studies. The review also takes account of the classification of some occupations (e.g. Painter) as carcinogenic by international bodies such as IARC without any specification of the causative agent.

This review has been prepared, according to the principles of systematic review used by IARC and described in the preamble to the IARC monographs. The publications forming the core of the data reviewed were retrieved by the Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail (IRSST) according to the searches detailed in Annex 1. More than 340 publications were retrieved by the initial search and an additional 30 have been added to provide supplementary data in specific areas. Of the publications retrieved approximately 30% were eliminated from further consideration after an initial review, on the basis of the relevance of content. Papers on carcinogenic risk of iron and steel founding, coal, cobalt, coke production and coal tar were part of the set retrieved by the searches as potentially relevant to the review but no occupation could be identified within the shipyard population that indicated exposures relevant to those topics. These topics and papers are not therefore included in this review.

Many of the studies retrieved are epidemiological and the principles applied to their review are based upon those of Doll (1984)[1] who summarised the specific needs for epidemiological observations regarding occupational cancer and listed the requirements for establishing carcinogenicity from epidemiological evidence:

- Positive association between exposure and disease in groups of individuals with known exposure (case-control or cohort studies)
- That is not explicable by: bias in recording or detection, confounding, chance
- That is observed repeatedly in different circumstances
- That varies appropriately with dose and period of exposure

This proposed approach differs from that of IARC in two key aspects

- The addition of a requirement that the association should show an appropriate temporal relationship between exposure and effect
- The omission of a requirement that the association should be strong (no longer stipulated by IARC)

Studies reviewed in this document relate to cancer potentially associated with occupational exposure and fall essentially into two types:

- Those following a cohort of workers with common exposures and analysing the disease rates or mortality in that group compared with a selected comparator population.
- Those taking a collection of cases of a particular cancer and examining the profile of the occupation and exposures of those cases compared with a selected comparator group. Depending upon the precise design and data available these may take different forms referred to variously as case-control, case-referent or registry-based studies.

Since some studies have greater power than others it has been an objective of this review to provide some insight into the quality of each study mentioned.

If fully detailed occupational and exposure data have been collected during the working life then these provide a strong basis for analysis of both types of study. However, the changing working conditions in many occupations mean that data are often not available for the whole employment period and exposure years are not all equal. Change of occupation during the working life of an individual is not always fully recorded, thus again potentially altering the exposure to substances or procedures of concern. The frequent habit of taking a single time-point statement of occupation as the classification element in an analysis is bound to be an inaccurate representation of exposure relative to chronic diseases. Unfortunately there are no documented demonstrations of just how inaccurate these assessments may be. Very few studies include exposure data collected independently at the time of exposure and depend entirely on recall for exposure classification.

Within this review an association between occupation and cancer is not considered demonstrated in a single study if the lower 95% confidence limit of the risk estimate falls below unity, regardless of the magnitude of that risk estimate. Where multiple studies are available due

account is taken of the reproducibility of findings, dose-response relationship and, where available, any meta-analysis of available data. It is recognised that data may show consistent trends but without firm significance due to small samples size and such results are also taken into account in any conclusions reached.

2. SHIPBUILDING AND OCCUPATIONAL EXPOSURES

Shipyards and dockyards are places which repair and build ships such as military vessels, cruise liners or other cargo or passenger ships. For the purpose of this review the concept of shipyard work is considered to embrace both construction and repair/maintenance of steel ships. The construction and maintenance of timber ships has received little attention in the epidemiological literature, however it may be that workers in shipyards were originally employed in the construction of wooden vessels and exposed to hazards not found in modern yards dedicated to steel ships. The construction techniques and practices most likely to be reflected in current occupational cancer rates are those applied in the last half of the 20th century.

The construction of boats and yachts of materials such as wood, with fibreglass reinforced plastic, composite, aluminium or steel-reinforced cement are not included in the review since specific relevant data were not identified.

Although many publications have reported on the risks and/or incidence and mortality rates of a range of potentially occupationally-related diseases in shipyard workers the current review concentrates on those that have studied cancer risks within this population. To set these data in context the nature of ship-building and the worker exposures that may result are briefly summarised to the extent that available information allows.

The published studies of cancer rates among shipyard workers in general are reviewed followed by separate review of three specific exposures which have been suggested as potentially influential in occupational cancer risk for shipyard workers.

2.1 Shipbuilding techniques

Modern shipbuilding makes considerable use of prefabricated sections. Entire multi-deck segments of the hull or superstructure will be built elsewhere in the yard, transported to the building dock or slipway, and then lifted into place. The most modern shipyards pre-install equipment, pipes, electrical cables, and any other components within the blocks, to minimize the effort needed to assemble or install components deep within the hull once it is welded together (Wiki 2010). The techniques relevant to this review are however those employed over the period since 1940 when ships have been produced almost exclusively of welded steel. Welding replaced drilling and hot riveting after World War II. The use of alloyed steel increased in the 1970's when the construction of specialist tank ships such as gas carriers increased. Alloyed steel could contain nickel and chromium. Stainless steel is used extensively in building ships with nuclear propulsion and in cryogenic liquid container ships. Lead (to provide radiation shielding) is used extensively in construction of nuclear-powered vessels and submarines (Burton 1984)[2].

Steel plates are blasted and coated to prevent corrosion. Nowadays, shipbuilders order plates with coating primer applied by a steel mill to prevent corrosion during transport and storage. In other cases a plate is blasted clean when it arrives and a coat of primer is applied on site. In

subsequent operations stiffeners and stubs are welded to plates and plates are welded together. The primer is either welded over or the primer is ground or blasted before welding.

All ships need maintenance and repairs. A lot of maintenance is carried out while at sea or in port by ship's staff. However a large number of repair and maintenance work can only be carried out while the ship is out of commercial operation, in a ship repair yard.

2.2 Occupations and exposures

Worker's exposure is generally described in epidemiological studies as a cumulative dose mg/m^3-years, based on job-title average exposure multiplied by the duration in years. Sometimes data are given in other forms such as an estimated annual average concentration e.g. mg/m^3. The measurement results, given in some publications, describe concentrations during the sampling period, and in many cases they give only a crude indication of annual average exposures.

Examples of measured concentrations of some known or potential carcinogenic hazards are presented in Table 1. The figures given are only illustrations of potential exposures; the variation of exposure between and within a shipyard in different time periods has been large. It should be noted that exposure concentrations of all agents have a time trend over the period of interest of this review, influenced by factors such as materials and techniques used, and ventilation.

Table 1.

Exposure of workers to carcinogenic hazard in shipyards.

Carcinogen / Suspect carcinogen	Job title/task	Year	Concentration (range)	Reference
Asbestos	Asbestos removal shipyard	1968	29-1040 fibres/cm^3	Williams et al., 2007[3]
	Removal of pipe lagging	1972	7-896 fibres/cm^3	
	each blue-collar worker	1945-1975	> 5 fibres/cm^3 annual mean	Burdorf & Swuste, 1999[4]
	specific blue-collar workers	1976-1985	2-5 fibres/cm^3 annual mean	
	specific blue-collar workers	1986-1975	< 2 fibres/cm^3 annual mean	
	Insulators in a naval shipyard, USA	1945-1973	100 fibre-days/cm^3 # (0,42 f/cm^3 * 240 days*1 year)	Zaebst et al. (2009)[5]
	Pipefitters in a naval shipyard, USA	1945-1978	20-100 fibre-days/cm^3 # (0.08-0.42 f/cm^3 * 240 days*1 year)	
	welders	1945-1956	8-20 fibre-days/cm^3 #	
		1957-1967	80 fibre-days/cm^3 #	
	welders	1982-1993	0.9 fibre-days/cm^3 #	
Benzene	painters, repairmen, carpenters	<1975	Not known but considered high	WHO/IPCS 1993[6]
Cadmium	plumbers, repairmen	<1985	10-250 µg/m^3 at breathing zone during shipboard brazers	NIOSH 1988[7]
Coal tar pitch	painters, repairmen		coal tar pitch was still used as pigment in black paints in the 1990s[8]	IARC,1987[9]
Chromium(VI)	painters, welders, sheet-metal-workers, fitters, repairmen	>1970	210 µg/m^3 8 h TWA as Cr (welding of stainless steel with covered electrodes) 20 µg/m^3 mean (gas shielded welding)	Ulfvarson 1978[10]
Lead	repairmen, painters, welders, sheet metal-workers, fitters, plumbers	Use of lead pigments decreased	lead in blood among demolishers 49 µg/dl, average	Tola and Karskela 1976[11]
			35 µg/dl, mean (n=28) shipbuilding	Landrigan and

Table 1.

Exposure of workers to carcinogenic hazard in shipyards.

Carcinogen / Suspect carcinogen	Job title/task	Year	Concentration (range)	Reference
		after 1970s	and repair	Straub 1985[12]
			21 (7-47) µg/dl, mean (n=30), boat builders	Grant, Walmsley et al. 1992[13]
			62% of paint removers exposed above 50 µg/m^3	Zedd, Walker et al., 1993[14]
Nickel	welders, sheet-metal-workers, fitters, repairmen, painters	>1970	25 µg/m^3 , mean in shielded metal arc-welding of stainless steel	Ulfvarson, 1981[15]
Metal-working fluids	mechanics, engine-room workers		No published data	IARC 1984[16]
Quartz	sand blasters	<1975	Not known	IARC1997[17] Goldsmith et al. (1982) [18]
Solvents including chlorinated hydrocarbons	painters, carpenters, wood-workers, engine fitters and mechanics, maintenance mechanics	<1975	Not known but considered high before 1970	IARC 1989[19]
Welding and thermal cutting fumes (total particulates)	welders, sheet metal workers		10-400 mg/m^3 in a ship	Kalliomaki, Alanko et al., 1978 ; Ulfvarson, 1981[15;20]
		1990's	2,3 mg/m^3 mean in shipbuilding, all welding methods	TWI 2010[21]
		1945-1993	80-100 mg-days/m^3 # (0.3-0.42 mg/m^3 * 240 days* 1 year)	Zaebst et al (2009)[5]
	All shipyard workers in a naval shipyard, USA	1945-1993	7-9 mg/m^3 #	Zaebst et al (2009)[5]
Wood dust	carpenters, wood workers		Not reported in shipyards	Krstev, Stewart et al., 2007[22]
Electromagnetic radiation (EMR)	Sheet metal-workers, welders		Not known	Skotte & Hjollund, (1997)[23]
Ultraviolet radiation (UVR)	welders		Not known	Dixon & Dixon, (2004)[24]
Ionizing radiation	constructers and repairers of nuclear-powered ships, industrial radiographer		Not known	Matanoski et al., (2008)[25]

estimated cumulative annual geometric mean exposure

Annual exposures to asbestos, lead, quartz and welding fumes have all decreased (negative trend) in the period 1950-2000, whereas exposure to Cr (VI) and Nickel may have increased, due to the growing use of alloyed steel. Exposures may also be associated with one another (e.g. asbestos exposures were reported to be moderately or strongly associated with welding fume exposures in a shipyard by Zaebst et al, 2009[5]).

The above Table 1. provides an illustration of the data available on the known carcinogenic hazards present in shipyards. It does not cover all the occupations and exposures which may occur in shipyards but there is no indication in the available data that any significant exposures relevant to carcinogenic risk in shipyard workers have been ignored.

It must be considered that job category may give only a partial understanding of total exposure to any hazard since workers in near-by areas may also be exposed, particularly when the work is carried out in enclosed spaces with limited ventilation. This is particularly true of asbestos where air-borne fibres can be dispersed widely in a working environment.

The following sections summarise the known background regarding exposure in shipyards to the main identified hazards.

2.2.1 Asbestos

The hazard of asbestos has been present in shipyard work for many years and certainly over much of the span of this review. The shipbuilding industry has traditionally used asbestos to insulate boilers, steam pipes, hot water pipes, and incinerators. Asbestos-containing construction sheets were also used until the end of 1970s and in other situations asbestos was sprayed *in situ*. All asbestos types were used in shipyards, including chrysotile, anthophyllite, amosite and crocidolite. Cancer risks from asbestos exposure began to become evident in the 1940s and an occupational exposure limit of 5mppcf (equivalent to approximately 30 fibres/cm^3) was set in the USA by ACGIH in 1946. For most workers relevant precautions to reduce exposure were not generally put in place until the 1970s and time would show that the initial assessment of a safe working level was rather optimistic with the 8-hour permitted exposure limit (PEL) gradually reducing to 0.1 fibres/cm^3 by 1994.

Exposures from 1920 onwards were generally poorly documented and exposure to asbestos was particularly widespread amongst those working in confined spaces on ship construction from mid-1930s until mid-1970s, although details of exposures are generally not available. During World War II, many workers employed in shipyards were heavily exposed to asbestos. In later years, those who worked around asbestos–contaminated pipes, boilers, and other items in shipyards were also exposed to asbestos dust; overhauling old ships, posing a risk of asbestos exposure for all workers in confined spaces, regardless of their job title. Higher exposures apply to certain occupations working directly with asbestos products (e.g. lagging, plumbers), but amongst the studies of shipyards there is little historic monitoring of actual exposure of individual workers. This indicates/suggests that asbestos exposure was relevant for most shipyard workers, although some specific occupations will have been exposed to much higher concentrations than background levels.

Exposure to asbestos in all occupations has been reviewed by Williams et al., 2007[3] who demonstrate that exposures of those working with asbestos before 1970 were around 2-5 fibres/cm^3 but were two-fold higher for shipyards in the USA and even higher for UK shipyards, where asbestos was sprayed. After the introduction of improved industrial hygiene practices in the 1970s the exposures for those working directly with asbestos products were reduced by between two and five-fold. Some measurements of exposure to asbestos fibres in shipyard workers are presented in Table 2 below:

Table 2.

Air concentration of asbestos in shipyards

Job title	Task	Mean (f/cm^3)	Range (f/cm^3)	No of samples	Shipyard	Year of study	Reference
Insulator	Removal of pipe lagging	152.3	7-896	22	Naval Dockyard UK	1972	Harries 1971[26]
Insulator	Removal of sprayed crocidolite	226.4	23-493	26	Naval Dockyard UK	1972	Harries 1971[26]
Insulator	Application of pipe lagging	8.9	0.1-55	41	Naval Dockyard UK	1972	Harries 1971[26]
Labourer	Removal of amosite from boiler room		29-1040		Naval dockyard UK	1968	References cited by Williams et al., 2007[3]
Labourer	Bagging asbestos debris		106-3815		Naval dockyard UK	1968	
Insulator	Installation during overhaul	100*	21-243		Naval dockyard USA	1970	
Insulator	Mixing cement	344*	163-540	8	Naval dockyard USA	1970	
Pipefitter	Hand shaping	0.13	<0.03-0.3	10	Naval dockyard USA	1978	
Pipefitter	Removal and clean-up	0.13	<0.06-0.39	14	Naval dockyard USA	1978	
Electrician	Cabling		<0.01-0.07	30	Navy vessels USA	1993	
Pipefitter	Machine punching	0.11	SD 0.04	5	Naval dockyard USA	2006	

Note: analytical methods for fibre counts have improved with time thus values may not be directly comparable.

*Value converted from mppcf to f/cm^3 using a ratio of 1:6

2.2.2 Thermal cutting and welding

Before 1940 only a few workers welded. Riveting and welding were performed at the same time during World War II and the subsequent years with metal-arc welding (MAW) being the method mostly applied initially. Rutile and acidic coated electrodes were used in the 1940s but in the early 1950s were partly replaced by basic-coated electrodes, which remain the most frequently used today. Gas-shielded welding was employed from the late sixties onwards.

Until the early 1970s welding was performed almost exclusively on mild steel. Welding of stainless and alloyed steel became more and more common in the late 1970s, particularly in pipe welding and in construction of special ships e.g. tankers.

Sheet metal workers cut and shape metal sheets by thermal cutting such as flame, plasma or laser cutting. Fumes formed during thermal cutting contain metal oxides, nitrogen oxides and carbon monoxide.

Composition of cutting/welding fumes

Welders are exposed to a range of fumes and gases. In arc welding, composition of the welding fumes depends upon the base material, electrode, and electrode coating. Welding fumes consist of gaseous and solid products. Gaseous components are mainly nitrogen oxides, carbon dioxide, carbon monoxide, fluorine compounds, and ozone. About 90% of particulate emissions originate from electrodes. Fume particles typically have a diameter of less than 1 µm. The fume concentration in the breathing zone of the welder depends on many factors, e.g., type of base material, type and dimensions of the electrodes, current, construction of the blocks to be welded (e.g. coatings), work location (confined space, open area), local ventilation, position of the welder, use of personal protective equipment (Table 3).

Table 3.

Examples of total particulate fume concentrations in the breathing zone of welders during different work situations (mild steel and basic electrodes) (Kalliomaki, Alanko et al. 1978)[20]

	Range of fume concentration (mg/m^3)
Ship	
Confined space	100-400
Installation of a block, open space	10-50
Installation of a block, partly closed	50-200
Welding shop, open space	
Horizontal seam, welder on his knees	10-60
Vertical seam	5-10
Inside of a block	50-200
Background sampling in the shop	2-10

According to the TWI[21] database, the mean of total particulates during welding (different methods, n=488) was 2,3 mg/m^3 in shipbuilding in the 1990's (TWI 2010), but this is a general value which will not be representative of work in confined spaces.

A study by Wurzelbacher et al. (2002)[27] measured exposure of 3 workers to particulates during normal welding shifts of confined space cells in a shipyard. The results were measured under two types of ventilation conditions using local exhaust systems (LEV) or direct fan ventilation (DV); workers wore the recommended personal protective equipment and the

samples were collected by personal sampling. Valid results were only obtained for two workers due to a failure of the third sampling system. LEV results gave mean values of 8.15 and 16.02 mg/m^3 while DV results were 30.32 and 57.80 respectively indicating the LEV was a more satisfactory ventilation system.

Chromium and nickel

In welding of stainless or other alloyed steel, fumes may contain significant amounts of Chromium (VI) and Nickel compounds. The percentage of Cr (VI) in fumes depends on the welding process. In shielded metal arc welding, 73% of Chromium in the fumes was reported to be as Cr (VI) (Ulfvarson 1981)[15].

2.2.3 Lead

Blood lead levels reported in workers repairing and demolishing ships (Table 1) are significantly higher than the current recommended upper occupational exposure limit of 30 µg/100ml (ACGIH, 2011, Guide to Occupational Exposure Values). The welding and cutting of lead-bearing alloys or metals whose surfaces have been painted with lead-based paint can generate lead oxide fumes. The use of lead containing pigments has decreased since the 1970's but in demolishing and repair of old ships significant exposure to lead compounds is still possible.

2.2.4 Paints and solvents

Steel plates are blasted and coated to prevent corrosion. Although shipbuilders nowadays order plates with coating primer already applied in other cases a plate a coat of primer is applied on site. Subsequent operations may lead to exposure of workers to residues of the primer as dust or as part of welding fumes. Painters may also be exposed to toxic pigments and solvents as below although some of the components may no longer be in use:

Pigments

Anti-fouling (e.g. organo-mercury compounds, copper oxide, arsenic, organo-tin compounds) and anti-rust paint (e.g. chromates, lead oxide, zinc compounds, coal tar pitch in black paints) (Haglind 1972)[28].

Solvents

Solvents (e.g. aliphatic and aromatic hydrocarbons, various ketones) used in paints before 1970 were often by-products of town gas or coking plants. Such solvents especially aromatic solvents (e.g. toluene) could contain benzene (WHO/IPCS 1993)[6]. Dermal exposure to solvents (xylene and ethylbenzene) was demonstrated to be an important source of exposure for painters (Chang et al., 2007)[29].

A further source of solvent exposure is identified as degreasing solvents used in various shipyard operations (EPA, 1997)[30]. Chlorinated hydrocarbons such as trichloroethylene or methylene chloride may have been used e.g. for paint stripping or removing and in degreasing of metals.

2.2.5 Crystalline silica

Shipyard workers can be exposed to crystalline silica in the cleaning, painting and repair of ships and vessels which often involves sandblasting to prepare surfaces for new paint or to clean them.

Where shipyard workers are required to use sandblasting equipment on large ships, increasing the duration of exposure to crystalline silica dust they can be considered to have an exposure and consequent risk, similar to sandblasters.

2.2.6 Wood dust

Teak has been the common hard wood used for ship's decking, and many other hard woods have been used for interior coverings and furniture in ships between 1950 and 2000. Wooden wall panels and furniture were common before the strict fire protection regulations on ships. Soft woods may also be used for scaffolding and frameworks during ship construction. Any wood worker employed in shipyards is likely to have had mixed exposure to hard and soft wood dusts.

2.2.7 Ionizing radiation

Shipyard workers may be exposed to ionizing radiation in repair of nuclear powered ships (e.g. submarines, ice breakers) and in shops where contaminated components of ship materials are repaired. The building of nuclear powered ships began at the end of 1950's. All workers employed in these shipyards may have been exposed. Matanoski et al., (2008)[25] list job titles such as machinists, nuclear engineers, pipe fitters, riggers, and welders as exposed to ionizing radiation.

Industrial radiography is a method of inspecting materials for hidden flaws by using the ability of short X-rays and Gamma rays to penetrate various materials. X-rays and gamma-rays were put to use very early, before the dangers of ionizing radiation were discovered. After World War II new isotopes such as caesium-137, iridium-192 and cobalt-60 became available for industrial radiography, and the use of radium and radon decreased. Radiography is used in weld inspection[4]. If strict safety measures are not followed, operators may be exposed to high doses.

[4] http://en.wikipedia.org/wiki/Industrial_radiography

2.2.8 Other exposures

Exposures in different shipyards may differ depending on the methods and materials used. In this review we have described the most common exposures. An example of another exposure that may have occurred is exposure to PCB that has been detected in dismantling of inactive nuclear submarines commissioned prior to 1970 (Still et al., 2003)[31].

Non-ionizing radiation

Non-ionizing radiation is the term used to describe the part of the electromagnetic spectrum covering two main regions, namely optical radiation (ultraviolet (UV), visible and infrared) and electromagnetic fields (EMFs) (power frequencies, microwaves and radio frequencies).
In shipbuilding, welders may be exposed to extremely low frequency magnetic field (MF) and ultraviolet radiation.

Magnetic fields

Welders are exposed to extremely low frequency magnetic field (MF) caused by welding high currents in cables. An example of the flux densities measured among welders in metal workshops and in a shipyard shows that metal welders' daily mean exposure (0,5 μT) in metal workshops was significantly lower than that of shipyard welders (7,22 μT) (Skotte & Hjollund, 1997)[23]. There are significant differences between exposures to magnetic fields in different subgroups of welders. Also reported measured magnetic flux densities differ significantly in published studies (Skotte & Hjollund,1997[23]; Sakuzara, Iwasaki et al., 2003[32]; Man & Shahidan, 2008[33]) . Many factors influence on the measurement results such as the welder's distance to the cable, sampling period, welding parameters, and the time actually welded making it difficult to estimate exposure levels.

Ultra violet radiation

Ultraviolet radiation (UVR) includes the wavelengths: ultraviolet A (UVA) (400–315 nm), ultraviolet B (UVB) (315–280 nm) and ultraviolet C (UVC) (280–100 nm). Over 98% of solar UVR exposure is in the form of UVA, whereas most of UVR is in the form of UVB and UVC in arc welding. UV exposure of welders is increased with decreasing proximity to the arc, increased arc energy, increased arc duration, higher current and certain angles of plate reflection. Different welding processes produce different UV exposure. The most intense UV exposure is often associated with welding aluminium or stainless steel where gas metal arc (MIG) or gas tungsten arc (TIG) processes are used. Also other workers in the vicinity of welders can be exposed to high UV levels. Exposure to UVR has a positive trend during the period 1950-2010 due increased use of MIG and TIG welding and aluminium in shipbuilding.

3. CANCER STUDIES AMONG SHIPYARD WORKERS

The published studies of cancer rates among shipyard workers are reviewed, followed by separate review of three specific exposures which have been suggested as potentially influential in occupational cancer risk for shipyard workers.

3.1 General studies

Studies carried out to determine whether there were generally any excess risks of cancer among shipyard workers are reviewed in this section. All original studies are summarised in Table 4 and described in the text, while reviews that contributed no original data are described briefly in the text according to their contribution to our final interpretation but are not detailed in this Table. The quality of studies varies considerably. While all studies are reported we have evaluated each study's potential to contribute to the understanding of cancer risk among shipyard workers.

A preliminary study by Blot et al. (1979)[34] compared cancer mortality rates in US counties with shipyards with rates in 80 US counties with no such activity. Respiratory cancer rates were higher in most shipyard counties than either the control counties or the general US national population, with a more consistent pattern in Southern Counties. There was some indication of higher rates for oro-pharyngeal, oesophageal and gastric cancer with some variation between different parts of the USA, although the differences were small. This study had a number of deficiencies in structure and served primarily as an indicator of a potential association of shipyards with excess cancer risk, but may be quite unreliable in respect of particular types of cancer or occupation. The results served primarily as a trigger for further investigation. A more detailed case-control study (Blot, 1978)[35] based on data from death certificates and hospital cancer registries in the area of shipyards is summarised in Table 4. The structure of the study group had some limitations, being drawn from three different locations over different time periods, with most of the data on occupation and lifestyle coming from next-of-kin interviews. This makes any detailed conclusion about specific occupational risks difficult but does provide some evidence of an overall excess of lung cancer among shipyard workers compared with contemporary patient controls.

Rossiter & Coles (1980)[36] studied cancer mortality in a group of workers employed in the Devonport UK Naval Dockyard on 1st January 1947, but limited the study population to men born on or after 1st January 1910. The cohort was followed until the end of 1978. In this workplace the use of asbestos reached a maximum in the 1950s and diminished throughout the 1960s. The high numbers of deaths from mesothelioma were not concentrated in any of the job categories studied, however the analysis is rather limited.

Mortality in shipyard workers who were members of a metal trade union in Greater Seattle USA and had worked in shipyards for a minimum of three years between 1950 and 1973 was the subject of an analysis by Beaumont & Weiss (1980)[37]. The cohort consisted of 8679 workers of whom 2019 had died and the division into job categories is shown in Table 4. Expected numbers of deaths were based upon general US mortality rates. Death rates due to lung cancer were stated

to be similar for the local and US national population. In the whole shipyard population there was a significant ($p < 0.01$) excess of respiratory and circulatory diseases, also of mental, psychoneurotic and personality disorders. The only cancer mortality rates showing significant elevation were of the respiratory tract and the mortality rates of respiratory cancer related to specific occupations are given in Table 4. The respiratory cancer rates were not broken down into type. Total respiratory cancer in welders was in excess of expected but the difference was not significant. However, an exposure/response analysis by time since first exposure showed a significant difference between welders, boilermakers and an unspecified group of others. Respiratory hazards were listed for welders in this study as fume containing oxides of iron, zinc, lead, and chromium plus carbon monoxide, nitrogen dioxide and ozone. The potential exposure to asbestos was also noted and the presence of three cases of asbestosis indicates some exposure but with no further detail as to when and where exposure occurred. Since actual exposure data for the population are not available no judgement could be made on the causative agent, equally no allowance could be made for smoking. As the emphysema rates in the group of welders were no higher than those of the general population this suggests that the excess lung cancer cases were unlikely to be due to smoking alone. Due to the lack of exposure data and failure to adjust for major confounders such as smoking, the results of this study cannot be considered as more than a potential confirmation of the association of shipyard work with respiratory cancer.

A cohort of shipyard workers from the US Naval Shipyard at Pearl Harbour was followed for up to 24 years and divided into two groups depending on the estimated exposure to asbestos (Kolonel et al., 1980)[38]. The study is summarised in Table 4 and did not adjust for smoking as a confounder, however the data did demonstrate a relationship between duration of exposure to asbestos and relative risk of lung cancer, with a maximum Relative Risk (RR) of 1.7 after 20-24 years of exposure. The follow-up period was a maximum of 24 years and in that time no cases of mesothelioma had appeared among the asbestos workers. However in the 6 years following the full analysis three cases of mesothelioma were seen. This study is too short for useful quantification of the mesothelioma risk and also does not take account of any exposure prior to work in the shipyard.

Hoiberg & Ernst (1981)[39] reported an analysis of cancer rates among naval personnel admitted to hospital between July 1965 and December 1976 and categorized them into 12 occupational groups. Although the occupational categories used in the analysis were rather broad the category "Construction/manufacturing" had the highest overall cancer rates and differed from other occupations particularly in rates of buccal/pharyngeal, skin and trachea/lung cancer. The study made no adjustment to rates for any aspect of lifestyle which might have acted as a confounder thus is of limited value in assessing occupational risks.

A study of mortality patterns in 107 563 deaths from a cohort of 293 958 US Veterans aged 31-84 (Blair et al., 1985)[40] identifies some associations relevant to occupational cancer risk in shipyards. Since data were available for smoking habit at two time-points these were used to categorise mortality ratios; since the crude and smoking-adjusted Standardised Mortality Ratios (SMRs) were similar only crude values were presented in the publication.

Significant associations among veterans but which may be relevant to shipyard working were found for:

Stomach cancer	Carpenters
Lung cancer	Plumbers and Pipe-fitters
Rectal cancer	Mechanics & Repair-men
Lung cancer	Workers in the shipbuilding and repair industry

Mortality among Welders (1027), Caulkers (235), Platers (557) and electricians (1670) employed at a UK shipyard between 1940 and 1968 was examined by Newhouse et al. (1985)[41] with reference to a set of personnel records from 1980. Lung cancer and mesothelioma were the only cancers analysed in any detail and rates for both showed an excess, related to occupation. Caulkers had a significant excess of all cancers, excluding mesothelioma (SMR 1.68; 95% CI 1.09, 2.49) this included lung cancer, excluding mesothelioma (SMR 2.32; 95% CI 1.33, 3.74). Cancer rates for other occupations showed some excess in the SMR values but all those SMRs were close to 1 with the lower confidence limit < 1 (Table 4). Mesothelioma rates were particularly elevated for electricians but at least one case occurred in each occupational category. This pattern tends to suggest universal exposure to asbestos among shipyard workers during the period of study, and highlights the difficulty of extracting effects for specific occupations when most workers experience some exposure.

Cancer incidence rates among a cohort of 4571 Norwegian shipyard workers were examined by Danielsen et al. (1993)[42] and a small excess of cancer in the total cohort, analysed by site showed significant excesses only of lung cancer and unspecified cancer. Although the rates for other cancers appeared elevated the difference from background was not significant. Analysis of lung cancer rates by occupation showed a significant excess only amongst welders and apprentices. Four pleural mesotheliomas were found but none among the welders. Detailed analysis of the data for 587 welders, allowing a 15 year development time for lung cancer, gave a higher Standardised Incidence Ratio (SIR) (3.08 CI 1.35, 6.08) with slightly higher rates for 255 high exposure (SIR 3.75 CI 1.38, 8.19) and 207 very high exposure (SIR 4.00 CI 1.10, 10.20) welders. The lack of full data on smoking habit and asbestos exposure compromise this study by reducing the potential to detect occupationally related cancers.

A study of another group of Norwegian shipyard workers (Danielsen et al. ,2000)[43] reported cancer incidence rates in a cohort of 4480 workers but found no evidence of significantly elevated rates of any type of cancer in any occupational category amongst this group or among any occupational sub-group. Four cases of pleural mesothelioma were found compared to 1.6 expected but there was no association with any specific occupation. Chen et al., 1999[44] studied dockyard painters, particularly looking for neurobehavioral effects of solvent exposure in the survivors of a cohort, but reported on the mortality in the cohort of 1292 painters, based on an analysis of death certificates. Cancer mortality rates were not found to be elevated compared with those expected, derived from the male population of Scotland. The small number of cases, lack of exposure information and brevity of reporting means that this study is of very limited value.

Puntoni et al. (2001)[45] studied a cohort of shipyard workers from a shipyard in Genoa, Italy and identified excess rates of lung and pleural cancer in many categories of occupation, mainly associated with general exposure to asbestos (Table 4). Mortality rates increased with duration of exposure and time since first exposure and unusually, welders showed no excess for either lung cancer or pleural mesothelioma (not shown in Table). Smith shipwrights and iron smiths had an excess of liver cancer, also associated with cirrhosis. Joiners, carpenters, caulkers and metallurgic workers had an excess of bladder cancer. While it is postulated that solvent exposure may have played a part in this excess there is inadequate evidence of specific exposures for a causative link to be made. The analysis of the 298 lung cancer cases, 32 cases of laryngeal cancer, 44 cases of bladder cancer, and 60 cases of pleural mesothelioma was extended to make some allowance for duration of exposure, with the conclusion that laryngeal and bladder cancer only reached significance after 40 years since first exposure and with a minimum of at least 25 years exposure. Pleural cancer is characterised by a shorter latency period than is lung cancer, with cases observed within 10-14 years from first exposure. However no allowance could be made for exposure prior to shipyard employment. Details of all the statistically significant cancer incidences are given in Table 4. Although this study gives some indications of occupationally-related cancer the lack of data on smoking habit and on exposures prior to shipyard employment significantly reduces the value of the results.

In an extensive study from a Coast Guard shipyard Krstev et al. (2007)[22] reviewed workers since first employment between 1950 and 1964 until 2001 and analysed rates for cancer among 20 different job categories. Overall cancer rates were elevated in the cohort compared with the local population background. The only cancer types showing overall excess in exposed shipyard workers (3038 of the cohort) were Respiratory system (SMR 1.28 95% CI 1.14, 1.43), Mesothelioma (SMR 5.39 95% CI 1.97, 11.74) and Lung (SMR 1.26 95% CI 1.11, 1.41). Those cancers showing significant increases related to occupation are shown in Table 4. All other occupations (*Carpenters, Painters, Transportation & material moving, Vehicle & garage mechanics or repairers, Ind. machinery repairers or maintenance, Electrical or electronic repairers, Other mechanics & repairers, Riggers, Freight, stock & material moving, Labourers, High level managers (e.g. superintendents, managers), Clerical, Engineers or Technicians, Professionals*) showed no evidence of a significant excess of cancer. The occurrence of isolated cases of mesothelioma in various occupational categories supports the likelihood that asbestos exposure and the consequent risk of asbestos-related cancers was a significant part of the occupational exposure in this study.

Most of the studies reviewed show some excess of lung and/or respiratory system cancer in shipyard workers, some also report excess cases of pleural mesothelioma. These findings lend support to the view that widespread exposure to asbestos, regardless of primary occupation may play a significant part in general shipyard cancer risk and may add to that for specific occupations within shipyards.

3.2 Summary

Studies available on shipyard workers are of variable quality and depth. The most informative studies are the ten cohort studies, of these seven[22;37;38;40-42;45] show excess of lung and/or respiratory system cancer in all shipyard workers and five[22;36;38;41;45] show some incidence of mesothelioma and one[37] reported a high incidence of asbestosis.

Six studies report cancer rates by occupation but the degree of discrimination varies with each study. Specific occupations with significantly increased lung/respiratory cancer risk (excluding mesothelioma) are welders[22;37;42], burners[37], platers[41], boiler makers[37], plumbers[40], pipe-fitters[22;40;45], caulkers[41], ship demolishers[45], metal workers/smiths[45], painters/careeners[45] and insulation workers[45]. Occupations with a significantly increased risk of mesothelioma were electricians[22;41;45], sheet metal workers[22], insulation workers[45], painters[45], plumbers[45], fitters[45], metal workers/smiths[45], ship demolishers[45], welders[41], caulkers[41] and platers[41]. Since most of the occupation specific data came from two studies and the incidence of lung cancer and pleural cancer were strongly associated this provides further evidence for the role of asbestos in the aetiology of cancer in shipyard workers with little to suggest additional risk for specific occupations.

Historical information, old measurements (Harries, (1971)[26]; Williams, (2007)[3]) and constructed exposure matrices (Burdorf, (1999)[46]; Zaebst, (2009)[5]) suggest that exposure to all types of asbestos, regardless of primary occupation, may play a significant part in general shipyard cancer risk and may add to that for specific occupations within shipyards.

Some other cancers were identified with significantly increased risk in shipyard workers but although they may be exposure-related none of these were identified in more than one study. These cancers were cancer of stomach[40] (carpenters), rectum[40] (mechanics & repair-men), bladder[45] (metalwork), liver[45] (smiths), larynx[45](insulation-workers) and oral/naso-pharynx[22] (wood-workers). Evidence for other occupationally-related cancer is derived later in this review from study of similar occupations in other industries.

Table 4

Shipyard cancer studies

Reference (Location)	Cohort/Study characteristics: Numbers	Confounders Included in analysis and exposure data	No. of Deaths/ Cases	Exposure categories	Observed/expected or cases/controls	RR, OR, SMR, PMR or SIR (95% CI)	Comments
Studies of shipyard workers in relation to the general population							
Blot et al. (1979)[34] (49 US counties with shipyards)	Numbers not specified	No exposure data and no consideration of confounders	Not given	Respiratory cancer Oro-pharyngeal Oesophageal Gastric		RR 1.12 RR 1.18 RR 1.14 RR 1.10	Results of limited value but provide a basis for future studies. See text
Blot et al. (1978)[35] (Coastal Georgia)	458 lung-cancer cases 553 controls Data sources were: **diagnoses** at 1 hospital (1970-1976); 3 further hospitals (1975-1976) plus **death certificates** (1970-1974)	Smoking, age, race and residence taken into account in analysis No exposure data available	Deaths 216/187 Hospital cases 319/472	Overall Insulator, boiler maker Pipefitter Ship-fitter, steamfitter Welder, burner Rigger, Leader-man Machinist, machine operator, metal worker Labourer, construction Electrician Clerk, accountant, draftsman, guard Not specified	535/659 2/2 10/4 6/5 11/20 6/9 13/11 24/20 5/3 7/3 15/5	RR 1.6 (1.1, 2.3)* RR 1.2 RR 3.1 RR 1.5 RR 0.7 RR 0.8 RR 1.4 RR 1.5 RR 2.0 RR 2.8 RR 3.7	Risk estimates are for lung cancer only Confidence intervals not given for most results. Only 5% reported handling asbestos directly. * p = 0.01
Cohort studies							
Rossiter & Coles (1980)[36] (Devonport Naval Dockyard, UK)	6292 workers in 1947 with follow-up until 1978	No allowance for confounders is reported and unlikely from the data given. No exposure data.	1043	All cancers Mesothelioma Lung Cancer Occupation (No. of men): Asbestos lagger, sprayer (54) Painter afloat (519) Mason, welder, boilermaker etc (2152) Engine fitter, ship, fitter (1843) Skilled labourer (1508)	265/282.1 (265/255.6)[#] 31/0.5 (31/0.4) 84/119.7 (84/100.3) All Deaths 9/10.8 (9/10) 107/102.3 (107/94.5) 382/395.7 (382/365.5) 234/264.5 (234/243.8) 311/307.9 (311/284.6)	SMR 0.94 (1.04)[#] SMR 6.4 (7.7)*** SMR 0.7 (0.84) All Deaths SMR 0.83 (0.9) SMR 1.05 (1.13) SMR 0.97 (1.05) SMR 0.88 (0.96) SMR 1.01 (1.09)	***p < 0.001 [#] Figures in brackets in the deaths and SMR columns are related to regional expected values. There was no further analysis of the cause of death by occupation.
Beaumont & Weiss (1980)[37] (Seattle	8679 Union members who had worked in shipyards for at least 3 years	Smoking was not taken into account. No exposure data available	2019	Welders (3247)	SMR Figures are for respiratory cancer. (No of deaths) 529	Total SMR 1.31 > 20 yr latency SMR 1.69**	* p < 0.05; ** p < 0.01; *** p < 0.001 No other cancer

Table 4

Shipyard cancer studies

Reference (Location)	Cohort/Study characteristics: Numbers	Confounders Included in analysis and exposure data	No. of Deaths/ Cases	Exposure categories	Observed/expected or cases/controls	RR, OR, SMR, PMR or SIR (95% CI)		Comments
Shipyards)	between 01/01/1950 and 31/12/1973			Ship-fitters (1538)	345	SMR 0.57	SMR 0.53	showed any significant association with any shipbuilding occupation.
				Helpers (1070)	350	SMR 1.28	SMR 1.45	
				Riggers (801)	255	SMR 0.92	SMR 0.76	
				Mechanics (766)	118	SMR 0.92	SMR 1.26	No direct exposure to asbestos in this cohort but asbestosis incidence indicates that some exposure occurred.
				Burners (473)	124	SMR 1.28	SMR 1.12	
				Boilermakers (463)	169	SMR 1.57	SMR 2.03*	
				Others (321)	129	SMR 1.98*	SMR 3.18***	
Kolonel et al. (1980)[38] (Pearl Harbour Naval Shipyard, Hawaii)	7536 men either employed on 01/01/1950 or recruited between then and 1969 4779 exposed to asbestos 2757 non-exposed	Asbestos exposure determined by job description. **Exposed** group had at least 1 year of work in a trade with likely exposure. Comparisons are with expected values for the general population of Hawaii. No allowance for smoking in the analysis but some smoking data is available showing more smokers in the shipyard workers than in the general population	383 exposed 236 non-exposed	Exposed:				Figures given are mortality from lung cancer by duration of follow-up. There were no deaths from mesothelioma at the time of follow-up (1974), which was a maximum of 24yr since first exposure. Three deaths did occur between 1974 and 1980
				0-9 years	4/7.2	RR 0.6		
				10-19 years	18/17.8	RR 1.0		
				20-24 years	13/7.5	RR 1.7		
				Total	35/32.5	RR 1.1		
				Non-exposed:				
				0-9 years	5/4.4	RR 1.1		
				10-19 years	4/8.7	RR 0.5		
				20-4 years	3/3.5	RR 0.9		
				Total	12/16.6	RR 0.7		
Blair et al. (1985)[40] (US Veterans)	29 3958 US veterans aged 31-84 and active in 1953	Smoking information and occupation were obtained for 85% of the group by questionnaire in 1954 or 1957.	107 563 deaths up to January1 970	Stomach cancer				[#]Figures in brackets are for smokers only * p≤ 0.05 Figures are only given for those occupations relevant to shipyards and showing a significant association
				Carpenters	22/13.3 (16/7.2)[#]	SMR 165* (223)[#]		
				Rectal cancer				
				Mechanics & Repair-men	12/5.7 (6/3.4)	SMR 211*		
				Lung cancer				
				Plumbers & pipe-fitters	39/21.2 (35/18.6)*	SMR 184 (188)*		
				Workers in Shipbuilding & repair industry		SMR 180*		
Newhouse et al. (1985)[41]	1027 Welders 235 Caulkers	No information on smoking habits or	Welders1 95	Lung cancer excluding mesothelioma				
				Welders	26/22.9	SMR 1.13 (0.8, 1.57)		

Table 4

Shipyard cancer studies

Reference (Location)	Cohort/Study characteristics: Numbers	Confounders Included in analysis and exposure data	No. of Deaths/ Cases	Exposure categories	Observed/expected or cases/controls	RR, OR, SMR, PMR or SIR (95% CI)	Comments
(NE England Shipyard)	557 Platers 1670 Electricians Employed between 1940 and 1968; followed up in 1982	asbestos exposure. No confounders considered in the analysis	Caulkers 50 Platers 87 Electric.2 11	Caulkers	12/5.2	SMR 2.32 (1.33, 3.74)	
				Platers	12/12.1	SMR 1.00 (0.57, 1.61)	
				Electricians	35/33.6	SMR 1.04 (0.75, 1.33)	
				Mesothelioma			
				Welders	1		
				Caulkers	1		
				Platers	2		
				Electricians	9		
Danielson et al. (1993)[42] (A Norwegian Shipyard)	4571 shipyard workers including 623 mild steel welders employed from 1940 to 1979	Some awareness of smoking habits with 10-20% more smokers in the cohort than in the general population. Detailed age-related analysis of lung cancer rates among welders showed increased risk with increasing exposure. Welding fume samples in 1973 showed a dust level of 0.8-9.5 mg/m^3 with a median of 2.5 mg/m^3. Further analysis in 1985 gave figures of 0.6-22 mg/m^3 (median 2.6 mg/m^3). No data on asbestos exposure	1078	Total cohort , all cancers	408/361.3	SIR 1.13 (1.02, 1.26)	Welders also had an increased risk (SIR) of Melanoma, other skin cancer, gastric cancer and rectal cancer although none of these appears significant
				Total cohort , lung cancer	65/46.3	SIR 1.40 (1.08, 1.79)	
				Total cohort , unspecified cancer	23/14.2	SIR 1.62 (1.03, 2.43)	
				Lung cancer:			
				Welders	9/3.6	SIR 2.50 (1.14, 4.75)	
				Burners	3/0.9	SIR 3.33 (0.67, 9.77)	
				Metal workers	8/7.8	SIR 1.03 (0.45, 2.03	
				Machine shop workers	11/8.4	SIR 1.36 (0.68, 2.43)	
				Carpenters	11/6.5	SIR 1.69 (0.85, 3.05)	
				Transportation and production support	3/3.8	SIR 0.79 (0.16, 2.31)	
				Watchmen	5/3	SIR 1.67 (0.53, 3.90)	
				Office workers, foremen	1/2.5	SIR 0.40 (0, 2.24)	
				Electricians	2/1.2	SIR 1.67 (0.17, 6.00)	
				Riggers, Dockers	1/0.9	SIR 1.11 (0, 6.22)	
				Coppersmiths, plumbers	1/0.7	SIR 1.43 (0, 8.00)	
				Apprentices and temps pre,'57	14/7.1	SIR 1.97 (1.08, 3.31)	
				Special support pre,'57	1/1	SIR 1.00 (0, 5.60)	
				Rust-pickers	1/3.4	SIR 0.29 (0, 1.63)	
				Others	0/0.8		
Danielsen et al. (2000)[43] (A single Norwegian shipyard)	4480 shipyard workers including 861 welders first employed between 1945 and 1980	Air samples taken in 1973 showed welding fumes in work air to be 14.5 mg/m^3 (4.2-54.4) while in 1977 the comparable figure was < 1.5 mg/m^3 and in 1989 was measured at 1.5 mg/m^3. Cr and Ni	801	All cohort	45/51.3	SIR 0.88 (0.64, 1.17)	Lung cancer only.
				Welders	9/7.1	SIR 1.27 (0.58, 2.42)	
				Metal workers	13/13.8	SIR 0.94 (0.50, 1.61)	
				Machine shop workers	9/5.3	SIR 1.70 (0.78, 7.33)	
				Burners	2/2.4	SIR 0.83 (0.10, 3.01)	
				Plumbers	1/2.9	SIR 0.34 (0.01, 1.91)	
				Carpenters	3/3.9	SIR 0.77 (0.16, 2.25)	

Table 4

Shipyard cancer studies

Reference (Location)	Cohort/Study characteristics: Numbers	Cohort/Study characteristics: Confounders Included in analysis and exposure data	Cohort/Study characteristics: No. of Deaths/ Cases	Exposure categories	Observed/expected or cases/controls	RR, OR, SMR, PMR or SIR (95% CI)	Comments
		levels also available. Smoking habit was considered in the overall analysis		Electricians Transportation and production support Office workers, foremen	1/0.8 13/19.9 6/8.6	SIR 1.30 (0.03, 7.23) SIR 0.65 (0.34, 1.12 SIR 0.70 (0.26, 1.52)	
Chen et al. (1999)[44] (Scottish dockyard)	A cohort of 1292 painters employed in the dockyard paintshop for ≥ 1 year between 1952 and 1994	No exposure data and no evidence of allowance for confounders in the analysis.	205	All sites Oesophagus Stomach Colon Rectum Lung Prostate Bladder	58/53 2/2 5/4 4/3 3/2 23/21 6/3 4/2	PMR 1.10 (0.84, 1.43) PMR 0.87 (0.10, 3.06) PMR 1.19 (0.39, 2.78 PMR 1.20 (0.33, 3.08) PMR 1.42 (0.29, 4.16) PMR 1.08 (0.69, 1.62) PMR 2.25 (0.83, 4.89) PMR 2.19 (0.60, 5.60)	No increase in any cancer rates either total or analysed separately. (Included a cross-sectional study of neurobehavioral effects in survivors)
Puntoni et al. (2001)[45] (Shipyard in Genoa)	3984 shipyard workers employed between 1960 and 1981. Incidence rates compared with the general local population.	Known general exposure to asbestos, welding fumes, silica dust, PAH and solvents but no specific data. Exposure judged on the basis of main occupation. No allowance made for smoking or other confounders.	2376	All cancers Liver Larynx Lung Pleura Bladder Other cancers Ship demolishers, stakers, masons (851) Lung Cancer Pleural cancer Smith shipwrights, iron smiths (710) Liver Cancer Lung Cancer Pleural cancer Joiners, carpenters, caulkers metallurgic. work(597) Bladder Cancer Lung Cancer Pleural cancer Fitters (354) Lung cancer Pleural cancer Plumber, coppersmith (365) Pleural cancer Painters, careeners (319)	812/562.6 34/18.3 32/19.5 298/168.7 60/11.5 44/28.7 96/72.6 59 11 11 61 10 12 50 10 26 4 6	SMR 1.44 (1.35, 1.55) SMR 1.86 (1.29, 2.60 SMR 1.64 (1.12, 2.32) SMR 1.77 (1.57, 1.98) SMR 5.24 (4.00, 6.74) SMR 1.53 (1.11, 2.05) SMR 1.32 (1.07, 1.61) SMR 1.56* SMR 4.88* SMR 3.92* SMR 2.18* SMR 5.31* SMR 2.06* SMR 1.68* SMR 4.93* SMR 1.74* SMR 3.94* SMR 5.62*	The high number of pleural cancers in all occupations indicates an extensive exposure to asbestos either during this employment or some earlier job.

Table 4

Shipyard cancer studies

Reference (Location)	Cohort/Study characteristics: Numbers	Confounders Included in analysis and exposure data	No. of Deaths/ Cases	Exposure categories	Observed/expected or cases/controls	RR, OR, SMR, PMR or SIR (95% CI)	Comments
				Lung cancer			
				Pleural cancer	25	SMR 1.83*	
				Electricians (163)	8	SMR 8.54*	
				Pleural cancer			
				Insulation workers(82)	4	SMR 7.98*	
				Larynx cancer			
				Lung cancer	3	SMR 8.52*	
				Pleural cancer	10	SMR 3.13*	
					3	SMR 13.68*	
						*p < 0.05	
Krstev et al. (2007)[22] (US Coast Guard Shipyard)	4702 Cohort employed between Jan 1950 and December 1964 and followed up to 2001.		3331	Electricians	Mesothelioma (2)	SMR 14.53 (1.63, 52.47)	313 subjects were lost to follow-up. Only job categories with significant cancer rates are shown.
				Machinists (metal & plastic)	Lung Cancer (30)	SMR 1.60 (1.08, 2.29)	
				Sheet metal workers	Mesothelioma (2)	SMR 16.65 (1.87, 60.12)	
				Woodworkers	Oral/Naso-pharyngeal (6)	SMR 6.20 (2.27, 13.50)	
				Ship-fitters, welders, cutters	Lung Cancer (85)	SMR 1.34 (1.07, 1.65)	
Cross-sectional/registry studies							
Hoiberg & Ernst (1981)[39] (US Navy Personnel)	3351 naval enlisted men admitted to hospital with neoplasms July 1965 to December 1976	No allowance made for age although there was some difference between the average ages in occupation categories.	162	All			#rate per 100,000 population per annum
				Total Malignancy	47.6#		
				Lung	3.5#		
				Construction			
				Total Malignancy	72.0#		
				Lung	7.4#		

3.3 Asbestos and cancer

In view of the potential extensive involvement of asbestos exposure in cancer rates among shipyard workers this topic is given specific coverage in the following section. While cancer is the end-point of concern in this review, asbestos exposure results in other chronic diseases which may be used as an exposure indicator by compensation bodies; the evidence for the role of these diseases in identifying asbestos exposure is summarised by O'Reilly et al. (2007)[47].

Much of the data on shipyard occupational cancer is based on workers first monitored in the last quarter of the twentieth century. The majority of epidemiological literature relevant to this review has been published since 1970 and this reflects the results of exposure occurring from about 1920 onwards. It is within this context that the relationship between asbestos and cancer is reviewed.

IARC[48] first reviewed available data in 1977 and a later review of past opinions in IARC Supplement 7 (1987)[49] provides a succinct summary of the status of this substance. A more recent review by IARC has yet to be published but it was noted by Straif K. (2009) in a presentation[5] and reinforces the previous opinions including conclusions about larynx and ovary as additional sites for asbestos-related cancer. The evidence for an association between asbestos exposure and lung cancer, laryngeal cancer[50] and mesothelioma is so strong that IARC classifies asbestos in all forms as a human carcinogen. The background and supporting data for this conclusion are not analysed further in this review but quantitative aspects are considered later in relation to their relevance to shipyard workers. It has been argued by Churg (1986)[51] and McDonald & McDonald (1996)[52] that the risk for mesothelioma from chrysotile asbestos exposure, is significantly less than that for the amphibole types and this is supported by more recent evaluation of a larger data set Hodgson & Darnton (2000)[53]. A further evaluation of the same population (Hodgson & Darnton, 2010)[209] concluded the risk ratio of chrysotile: amosite: crocidolite to be 1: 100: 500 for mesothelioma and the chrysotile: amphibole ratio to be between 1: 10 and 1: 50 for lung cancer. However all forms of asbestos are classified as carcinogenic. However because the type of asbestos exposures experienced by shipyard workers are poorly characterised; the distinction regarding type of asbestos exposure will not be discussed further. Generally the latency from initial exposure to time of appearance of mesothelioma is longer than that for lung cancer; however there are mesothelioma cases resulting from brief intensive exposure to crocidolite.

While potentially all shipyard workers may have been exposed to asbestos Malker et al. (1990)[54] noted that plumbers, mechanics, painters and electricians had the highest excess risks of pleural mesothelioma. Huncharek & Muscat, (1990)[55] documented a range of occupational activities resulting in potential asbestos exposure including spraying of acoustic insulation, locomotive boiler insulation, building insulation and fire-proofing.

[5] http://www.docstoc.com/docs/75674124/The-IARC-Monographs

3.3.1 Lung cancer

It is established that lung cancer is causally related to asbestos exposure IARC (1977)[48] and there is also evidence that asbestos exposure and smoking have a synergistic effect on lung cancer rates. This interaction was considered by Langård (1994)[56] while evaluating the preventability of lung cancer in the Norwegian population. The conclusion that he reached is that asbestos exposure has been responsible for about two thirds of occupationally-related lung cancer in Norway. Although there is consensus that the combined exposure to both cigarette smoking and asbestos increases lung cancer risk the precise numerical link between smoking and asbestos-related cancer risk has not been determined. The relationship between smoking and asbestos is discussed by Berman & Crump (2008)[57] in a review of the EPA risk assessment model for asbestos-related cancers. Their conclusion, based on a published assessment by Berry & Liddell (2004)[58], is that the relationship is probably intermediate between multiplicative and additive. As a consequence the multiplicative model used by the EPA may overestimate risk for smokers and underestimate that for non-smokers; although the degree of overestimation is probably small.

Everatt et al. (2007)[59] examined the asbestos exposure history of lung cancer (298) and mesothelioma (4) patients in a Lithuanian hospital. Exposures were calculated, although in the absence of exposure monitoring before 1998 the basis for assessing airborne fibre concentrations for earlier exposures appears to depend on an unidentified German data base. The exposure to 25 “fibre years”, causes an approximately two-fold increased risk of lung cancer. The authors suggest that this value be used by various bodies for compensation calculations. Based upon this guide value the authors concluded that around 50 cases of lung cancer per year in Lithuania are associated with asbestos exposure.

Kishimoto et al. (2003)[60] report results of examinations of 120 lung cancer patients whose cancers were suspected of being caused by asbestos exposure. Presence of asbestosis, pleural plaques and asbestos bodies was reported and provided sufficient evidence for industrial compensation in all of these cases. The evidence required is defined as "patients who have worked in an environment where asbestos has been used for about 10 years or longer and in whom the severity of asbestosis is classified as Profusion Rate (PR) on chest radiography 1 or higher or in whom pleural plaques can be confirmed by chest radiography." Alternatively if asbestos bodies have been demonstrated in the lung the other conditions need not be fulfilled.

3.3.2 Mesothelioma

Evidence for the link between exposure to asbestos and occurrence of pleural mesothelioma, together with descriptive pathology are given by Baas et al. (1988)[61].The authors note however that a history of exposure to asbestos cannot be identified in all cases. However, background mesothelioma rates in the general population are low ($1/10^6$)[62]. The rare occurrence of this cancer in the general population and the more common occurrence in some categories of workers suggest an occupational cause. Studies which report on the occupational distribution of Mesothelioma are summarised below.

Kishimoto et al. (2004)[63] studied 106 cases of malignant pleural mesothelioma in Japan. All but six of these individuals had a history of occupational asbestos exposure and 51 had a history of shipyard work. Cases had a mean duration asbestos exposure of 17.2 ± 8.9 years. Latency was >31 years with a mean of 37.0 ± 13.3 years. Whether the occupational history of these cases is representative of the wider Japanese population, or of other populations of mesothelioma patients, is not known.

An indication that the controls introduced in the 1970s (which reduced levels of asbestos exposure) may be influencing cancer rates comes from a review of pleural mesothelioma by Davenport (1989)[64]. These predictions contrast with the more recent report of Jemal et al. (2000)[65] who conducted an extensive analysis of lung and mesothelioma cancer mortality rates in US counties, giving particular attention to those which contain shipyards. The trends which they identified suggest that mesothelioma mortality rates are rising amongst males in the shipyard counties although the rate of increase is slowing. Lung cancer rates, which include cancer of lung, bronchus, trachea and pleura, appear to be rising in females residing in these shipyard counties, which may reflect both lower rates of asbestos exposure and increased rates of cigarette consumption. This evidence for shipyard-related cancer is very indirect since no account is taken of individual occupation.

Bang et al. (2004)[66] also summarises trends in mesothelioma incidence and mortality rates, based on data from the US National Centre for Health Statistics. Although they identified 10 016 deaths from pleural neoplasms between 1979 and 1998, age-adjusted mortality rates actually declined from 2.8 / 10^6 to 2.3 / 10^6 during this period. Elevated incidence rates, associated with asbestos exposure, were found among workers in the ship-building industry as well as among those in the petroleum refining and construction industries. Among construction workers rates were particularly high for insulation workers, plasterers and boilermakers. These results were reported in more detail by Pinheiro et al., (2004)[67].

3.3.3 Laryngeal cancer

Laryngeal cancer has recently been acknowledged by IARC as an additional cancer type associated with exposure to asbestos (Straif, 2009)[50]. Within shipyard data there is only one report of excess cancer at this site (SMR 1.64; 95%CI 1.12, 2.32) from a study which acknowledged that the workforce had a high level of exposure to asbestos (Puntoni et al., 2001)

[45]. This study also showed a significant ($p < 0.05$) excess of laryngeal cancer in Insulation workers (SMR 8.52).

3.4 Exposure to ionizing radiation and cancer risk in shipyards

The possibility that shipyard workers exposed to ionizing radiation may have an increased risk of cancer from that exposure has been a subject of considerable study, summarised below. It should however be noted that this is a specific risk associated with work on ships with a known radiation hazard. Radiation exposure has occurred in some non-shipyard occupations for a considerable time and it is from these sources that information on occupational risk is mostly derived. The exposure of shipyard workers grew significantly at a time when awareness of occupational risks was also increasing thus the surveillance has benefitted from many of the lessons learned in other sectors but the direct consequences may not yet be evident in the exposed workers.

3.4.1 General reviews

The occupational cancer risks for radiologists and radiation workers were reviewed by Matanoski et al. (1984)[68] and the authors commented that exposure of shipyard workers is only to γ-radiation whereas other occupations who are exposed may be additionally exposed to x-rays or α-radiation. Any conclusions related to occupational cancer risk may therefore not be directly translated from other occupations to shipyards.

An overview of occupational radiation and cancer (Boice & Lubin, 1997)[69] summarised a wide range of occupational exposures including those reviewed in detail for shipyards in section 3.4.2 below. The conclusion regarding studies of shipyard exposures was that "while reassuring, they indicate that at the low doses involved the level of risk is accordingly low and perhaps not detectable by epidemiologic methods."

3.4.2 Ionizing radiation and cancer in shipyards

Exposure to ionizing radiation is only relevant to those shipyard workers who have been employed in yards working on construction or repair of nuclear-powered vessels or those involved directly in industrial radiography. Any risks for this sub-group will not be relevant to the general shipyard population who do not have such exposure.

A preliminary communication by Najarian et al. (1978)[70] on the subject of cancer among shipyard nuclear workers was based upon 1722 deaths among former workers at a US Naval shipyard. The death certificates were retrieved from the local registry for the period 1959 to 1977. Evidence for employment with radiation was only obtained from next of kin for one third of the deaths; remaining deaths were not categorised by this description. There is inadequate information on exposure to radiation of each individual or of exposure to other potentially confounding factors. The observed total number of cancer cases of 56 among the 146 deaths among workers classified as nuclear workers, was greater than the 31.5 expected from the

general population. Among these cancers there were 6 cases of leukaemia compared with 1.1 expected. The limitations of the study are detailed by the authors and the absence of so much background information on exposure clearly compromises the analysis, thus the study is not detailed in the following table. The deficiencies of this study are also the subject of some comments by Greenberg et al.(1983)[71].

In 1979 a preliminary report was issued from a NIOSH investigation[72] of the same shipyard following up the above results, utilising more direct evidence of exposures (Rinsky et al., 1981, 1988)[73;74]. Rinsky et al. (1981)[73] analysed data from a total cohort of 24 545 workers, employed between 1952 and 1977, and divided them into 3 sub-cohorts:

1. Exposed radiation workers (7615)
2. Non-radiation workers (15 585)
3. Unexposed radiation workers (1345)

Of the total cohort 1012 were lost to follow-up and 4762 had died compared with 5361 expected, based on average US mortality rates. For sub-cohort 1 the total cumulative radiation dose and time since initial radiation dose were known and used in the analysis. Deaths in the total cohort due to leukaemia and all lymphatic and haematopoietic neoplasms were lower than expected, as was total cancer mortality (Table 5). Analysis of tumour rates against the level of cumulative exposure showed no trends or differences suggestive of a relationship between ionizing radiation exposure and cancer incidence. While the lack of any evidence of excess cancer in the exposed population is reassuring the main weakness of this study is the relatively short duration of 25 years between first employment and last observation.

A further report by Rinsky et al. (1988)[74] used a case-control approach from the same cohort to investigate rates of lung cancer relative to exposure to radiation, taking account of exposure to asbestos and welding. The case series consisted of 405 individuals who died from malignant cancer of trachea, bronchus or lung, compared with 1215 controls. Radiation histories were available for 121 cases and 330 controls. For lung cancer cases the OR for a history of radiation exposure was 1.23 (95% CI 0.91, 1.67). Examining different levels of cumulative radiation exposures showed no dose-related trends; although the OR for the second to highest exposure group was statistically significant 1.81 (95% CI 1.05, 3.12). The difference was no longer significant when adjusted for asbestos and welding exposure but this may in part be due to the small numbers (Table 5). There was no relationship between time of first exposure to radiation and lung cancer but there was a significant OR for asbestos and welding combined. Two particular weaknesses of this study are the relatively short duration of follow-up since first exposure and the method of selection of controls from the cohort, which took only limited measures to match the cases and was also commented on as a weakness by the authors.

Silver et al. (2004)[75] reported a study of an enhanced cohort of 37 853 workers at a US naval shipyard (Portsmouth) which was divided into three sub-cohorts; monitored and exposed (11791); monitored but unexposed (1677) and non-monitored (24 385). Deaths were 12 393, 3223, 638 and 8532 for the total and sub-cohorts respectively. Smoking-related diseases, asbestosis and silicosis were analysed and no differences were identified between the sub-cohorts. Cancer deaths were slightly elevated in the full cohort (SMR 1.06 95% CI 1.02, 1.10) with the main excess occurring in the non-monitored sub-cohort (SMR 1.06 95% CI 1.01, 1.10) and the exposed sub-cohort (SMR 1.07 95% CI 1.00, 1.14). However no specific cause was

identified for these differences, although there was a slight excess of lung cancer cases in the exposed sub-cohort, which is investigated in a further study reported below[76]. Leukaemia was not in excess among unexposed workers but showed a strong association with exposure and results are presented in Table 5; a more detailed analysis is described in the additional study reported by Kubale et al. (2005)[77] below and also summarised in Table 5.

The slight excess of lung cancer noted in radiation-exposed workers by Silver et al. (2004)[75] was investigated by Yiin et al. (2005)[76] through an in-depth analysis taking account of confounding factors including, welding fume, asbestos, solvent and smoking. Due to lack of detailed information some of the adjustments are relatively crude; asbestos and welding fume exposure are based only on individuals with a complete monitoring record and job category is the base of potential exposure classification. Smoking history was not known thus socioeconomic status was used as a surrogate. The inclusion of all of these parameters in models for lung cancer risk left no relationship between lung cancer and external radiation exposure. The increased lung cancer rates were mainly attributable to a combination of smoking, asbestos and welding fume exposure. Lung cancer risk in the same shipyard was also investigated using a nested case-control study approach by Yiin et al. (2007)[78]and including adjustment for confounders such as age, socioeconomic status, welding fume and asbestos exposure, confirmed the previous conclusions that there was not a significant association between exposure to ionizing radiation in shipyards and lung cancer risk.

Kubale et al. (2005)[77] reported a case-control study which was a second follow-up to the study by Silver et al. (2004)[75] and investigated the relationship between leukaemia mortality and ionizing radiation at the same US naval shipyard. The 115 cases which occurred between 1952 and 1996 were matched with 460 controls from the same population of workers at the shipyard. The study took account of solvent exposure (benzene and carbon tetrachloride) although data on exposure to these solvents were limited. Mean radiation dose for cases was 39.0 mSv compared with 20.0 mSv for the controls while mean cumulative dose was 23.2 mSv for cases and 4.5 mSv for controls. Log-linear regression analysis showed a significant positive exposure-response relationship between leukaemia mortality and external ionizing radiation dose (OR 1.08 at 10 mSv exposure; 95% CI 1.01, 1.16) when adjusted for solvent exposure duration, radiation worker status and gender. The same model also showed a significant positive response between leukaemia mortality and solvent exposure duration (OR 1.03 at 1 year of exposure; 95% CI 1.01, 1.06). An Excess Relative Risk (ERR) of 23% (95% CI; 3%, 88%) per 10 mSv of external radiation exposure was concluded. A range of limitations of the study data was described by the authors mainly associated with the accuracy of exposure data.

A study by Schubauer-Berigan et al. (2007)[79] investigating the effects of ionizing radiation exposure on workers included a US naval shipyard as well as four nuclear weapons facilities. Exposure in this study was measured by bone-marrow dose which is the most strongly associated with leukaemia effects. The study also gathered information on exposure to benzene and solvents as potentially contributory factors to leukaemia incidence. Workers exposed to benzene at the highest level (work for > 200 hours at a level equivalent to or higher than the current OEL) had an 80% increase in leukaemia compared with the unexposed. After adjusting the rates for benzene exposure and for sex, those who had received more than 10 mSv of radiation had a RR of 1.45 (95% CI: 1.04, 2.01).There were higher risks per unit dose for those born after 1921 and those hired after 1952 compared with earlier times. When 22 cases of leukaemia of an

ambiguous type were eliminated from the analysis the additional risks were greater per unit dose than when all leukaemia cases were analysed; ERR per 10 mSv = 2.6% (< 1.03%, 10.3%) taking account of all confounders. A lag of 2 years provided the best fit when the data were modelled, including all workers and adjusting for sex; when those employed after 1921 were analysed separately the best fit lag period was 7 years. Schubauer-Berigan et al. (2007)[80] also reported a case-control study of Chronic Lymphocytic Leukaemia (CLL) drawn from the cohort and although there was a positive trend towards increased incidence with increasing dose the differences were not significant. The lack of significance may be in part attributable to the small numbers of cases in each exposure category.

Matanoski et al. (2008)[25] studied a sample of a very large cohort of 800 000 workers from 8 shipyards with a sub-cohort of 100 000 nuclear workers. The randomly selected sample included all nuclear workers with lifetime exposures of >5.0 mSv, 20% of nuclear workers with a lower lifetime exposure and 30% of non-nuclear workers; more details are given in Table 5. Analysis of deaths from lung cancer and leukaemia by methods of internal and external comparison showed no significant differences but there was a claimed dose-related trend in leukaemia rates despite some of the highest rates being found in non-nuclear workers. A high cancer rate in non-nuclear workers is put down to an enhanced healthy worker effect resulting from careful selection of nuclear workers. This study neither confirms nor refutes the suggestion that high-dose exposures to radiation may be associated with an excess risk of leukaemia.

Thus, based on the available data there is limited evidence that shipyard workers exposed to radiation at the highest level (> 10 mSv of radiation) may have an increased risk of leukaemia. The failure to demonstrate excess risks in some of the studies reviewed above may be due more to the limits of detection than to the lack of an association. Since some of the reported studies may have been too limited to detect small effects the excess relative risk of 23% (95% CI; 3%, 88%) per 10 mSv of external radiation exposure concluded by Kubale et al. 2005 [77] is considered to be consistent with all available data.

It should be noted that exposure to ionizing radiation will generally only be experienced by workers in those shipyards constructing or repairing nuclear-powered vessels since in other shipyards there is no potential for such exposures, apart from those directly employed in industrial radiography.

Table 5

Ionizing radiation cancer studies

Reference, (Location)	Cohort / study characteristics			Exposure categories	Obs/Exp or cases/controls	ERR, RR, OR, SMR, SRR or SIR (95% CI)	Comments
	Numbers	Confounders Included in analysis and exposure data	No. of deaths/ cases				
Cohort studies							
Rinsky et al. (1981)[73] (Portsmouth Naval Shipyard - PNS)	24 545 white male workers employed between 1952 and 1977; divided into three sub-cohorts	No confounders considered. Exposure data available on an individual basis for radiation.	4762	Total cohort			Expected rates are based on total US white male population
				All malignant cancer	977/1032.8	SMR 0.94 (0.89, 1.01)	
				Leukaemia	39/41.5	SMR 0.94 (0.67, 1.28)	
				Workers with mean radiation exposure of 2.779 rem (0.001-91.414) (7615)			
				All malignant cancer	201/218.5	SMR 0.92 (0.80, 1.06)	
				Leukaemia	7/8.3	SMR 0.84 (0.34, 1.74)	
				Non-radiation workers (15 585)			
				All malignant cancer	726/723.6	SMR 1.00 (93, 1.08)	
				Leukaemia	31/29.1	SMR 1.06 (0.72, 1.51)	
				Radiation workers with no exposure (1345)			
				All malignant cancer			
				Leukaemia	50/59.5	SMR 0.84 (0.62, 1.11)	
					1/2.3	Not calculated	
Silver et al. (2004)[75] (US Naval shipyard - PNS)	37 853 workers employed 1952-1992 monitored through 1996.	Confounding effect of solvent exposure was not considered. Smoking-related disease was at similar rates in all groups. The data suggest that exposure to asbestos and radiation may be linked in this facility.	12 393	Full cohort:			No excess of any other cancer in the radiation-exposed group.
				Leukaemia (115)		SMR 1.01 (0.84,1.22)	
				Exposed radiation workers			
				Leukaemia (29)		SMR 0.90 (0.60, 1.29	
				Exposure 0-< 1 mSv (5)		SRR 1	
				Exposure 1-10 mSv (10)		SRR 2.05 (0.77, 5.47)	
				Exposure 10- < 50 mSv (10)		SRR 2.98 (1.12, 7.97)	
				Exposure > 50 mSv (7)		SRR 5.13 (1.37, 19.19)	
				Unexposed radiation workers			
				Leukaemia (5)		SMR 0.79 (0.25, 1.95)	
				Non-monitored workers			
				Leukaemia (81)		SMR 1.08 (0.86, 1.35)	
Yiin et al. (2005)[76] (US Naval shipyard - PNS)	as Silver et al. (2004)[75] above	Adjusted for asbestos and welding fume exposure and socioeconomic status.		Unadjusted lung cancer mortality		ERR 1.13 (-1.44, 4.56)/10 mSv	Study addressed the excess of lung cancer deaths seen in the cohort
				Adjusted mortality rates		ERR -0.53 (-3.06, 2.59)/10 mSv	

Table 5

Ionizing radiation cancer studies

Reference, (Location)	Cohort / study characteristics			Exposure categories	Obs/Exp or cases/controls	ERR, RR, OR, SMR, SRR or SIR (95% CI)	Comments
	Numbers	Confounders Included in analysis and exposure data	No. of deaths/ cases				
Schubaer-Berigan et al. (2007)[80] (4 US weapons facilities and a naval shipyard)	Nested Case-control data from within cohort study described later[79]	Adjusted for smoking	43 CLL deaths and 172 control	Total external dose			In this study RR refers to Rate Ratio rather than relative risk
				0-< 1 mSv		RR 1.00	
				1-< 10 mSv		RR 1.09 (0.38, 3.42)	
				10-< 50 mSv		RR 1.65 (0.61, 4.99)	
				50-< 100 mSv		RR 2.55 (0.59, 11.0)	
				≥ 100 mSv			
				Linear model: ERR per 10 mSv*			
				0- < 2 years		RR -0.28 (< 0, 1.25)	
				2- < 5 years		RR -0.12 (< 0, NC)	
				5- < 10 years		RR -0.14 (< 0, 0.44)	
				10- < 20 years		RR 0.30 (< 0, 1.6)	
				≥ 20 years		RR 0.26 (< 0, 1.6)	
				* data for workers excluding those with exposure > 100 mSv			
Matanoski et al. (2008)[25] (Eight US Shipyards)	800 000 workers of whom 700 000 were non-nuclear. Analysis of a stratified random sample of: 28 000 ≥ 5.0 mSv 10 462 < 5.0 mSv 33 353 non-nuclear	No clear indication of what adjustment has been made apart from age.		External comparison			Figures are for age-adjusted lymphatic and haematopoietic cancer mortality. Similar analysis of lung cancer rate showed no significant differences or trends.
				≥ 5.0 mSv	50	SMR 0.82 (0.61, 1.08)	
				< 5.0 mSv	13	SMR 0.53 (0.28, 0.91)	
				Non-nuclear	84	SMR 1.1 (0.88, 1.37)	
				Internal comparison with 5.0-9.99 Msv group			
				≥ 5.0 mSv			
				5.0-		OR 1.00	
				10.0-		OR 3.23 (1.1,12.6)	
				50.0-		OR 2.94 (1.0, 12.0)	
				< 5.0 mSv		OR 1.71 (0.57, 7.2)	
				Non-nuclear		OR 3.58 (1.3, 13.5)	

Table 5

Ionizing radiation cancer studies

Reference, (Location)	Cohort / study characteristics: Numbers	Confounders Included in analysis and exposure data	No. of deaths/ cases	Exposure categories	Obs/Exp or cases/controls	ERR, RR, OR, SMR, SRR or SIR (95% CI)	Comments
Cross-sectional/registry studies							
Rinsky et al. (1988)[74] (Portsmouth Naval Shipyard - PNS)	405 cases that died from malignant cancer of lung, trachea or bronchus compared with 1215 individuals from the cohort who had not died from malignant cancer.	Cases were selected from the cohort described above[73] Confounding by welding and asbestos exposure taken into account crudely, since no exposure data were available.		Unadjusted cumulative radiation exposure:			
				Any history	121/330	OR 1.23 (0.91, 1.67)	
				0.0	21/60	OR 1.17 (0.68, 2.04)	
				0.001 - 0.999	62/190	OR 1.11 (0.77, 1.61)	
				1.0 - 4.999	25/47	OR 1.81 (1.05, 3.12)	
				≥ 5.0	13/33	OR 1.37 (0.68, 2.78)	
				Adjusted cumulative radiation exposure:			
				Any history		OR 1.18 (0.86, 1.62)	
				0.0		OR 1.13 (0.65, 1.96)	
				0.001 - 0.999		OR 1.07 (0.74, 1.55)	
				1.0 - 4.999		OR 1.68 (0.97, 2.91)	
				≥ 5.0		OR 1.23 (0.60, 2.51)	
Kubale et al. (2005)[77] (US - PNS)	115 leukaemia deaths (1952-'96), 460 controls.	Adjusted for solvent exposure		Solvent exposure duration		OR @ 1 year 1.03 (1.01, 1.06)	Solvent exposures based on very limited data
				External ionizing radiation		OR @ 10 mSv 1.08 (1.01, 1.16)	
Schubaer-Berigan et al. (2007)[79] (4 nuclear weapons facilities and one naval shipyard - PNS)	206 deaths from non-CLL (chronic lymphocytic leukaemia) compared with 823 age-matched controls	Benzene exposure ≥ 200 hrs was associated with non-CLL Leukaemia 1.82 (1.14, 2.85) and combined exposure to radiation and benzene increased the risk.		Total bone-marrow dose (including Plutonium) Two year lag, unadjusted:			Data for the naval shipyard are not separated from the rest but PNS contributed 27 cases and 108 controls
				0 - <1 mSv			
				1 - <10 mSv	28/141	OR 1	
				10 - < 50 mSv	71/350	OR 1.05 (0.65, 1.72)	
				50 - < 100 mSv	70/232	OR 1.61 (0.98, 2.70)	
				≥ 100 mSv	18/50	OR 1.89 (0.94, 3.72)	
					19/50	OR 2.05 (1.02, 2.62)	
				Two year lag, adjusted for sex:			
				0 - <1 mSv			
				1 - <10 mSv	28/141	OR 1	
				10 - < 50 mSv	71/350	OR 0.98 (0.61, 1.63)	
				50 - < 100 mSv	70/232	OR 1.41 (0.85, 2.38)	
				≥ 100 mSv	18/50	OR 1.65 (0.82, 3.28)	
					19/50	OR 1.74 (0.85, 3.51)	

Table 5

Ionizing radiation cancer studies

Reference, (Location)	Cohort / study characteristics			Exposure categories	Obs/Exp or cases/controls	ERR, RR, OR, SMR, SRR or SIR (95% CI)	Comments
	Numbers	Confounders Included in analysis and exposure data	No. of deaths/ cases				
Yiin et al. (2007)[78] (US Naval shipyard - PNS)	1097 deaths with lung cancer as an underlying cause and 3291 age-matched controls.	Multivariate analysis took account of potential confounders of Socioeconomic status, sex, age, and welding fume and asbestos exposure		Unadjusted:			Multivariate analysis used a 15-year lag.
				Exposure 0 -< 1 mSv	889/2794	Baseline	
				Exposure 1 - 10 mSv (10)	104/264	RR 1.23 (0.97, 1.56)	
				Exposure 10 -< 50 mSv (10)	69/141	RR 1.54 (1.14, 2.07)	
				Exposure > 50 mSv (7)	35/92	RR 1.21 (0.80, 1.77)	
				Multivariate analysis:			
				Log-linear (at 10 mSv)		RR 1.02 (0.99, 1.04)	
				Linear (per 10 mSv)		ERR 1.9% (-0.9%, 6.6%)	
				Dose ≥1 - < 10 vs < 1 mSv		RR 1.17 (0.86, 2.09)	
				Dose ≥ 10 - < 50 vs < 1 mSv		RR 1.45 (1.01, 2.09)	
				Dose ≥ 50 vs < 1 mSv		RR1.13 (0.072, 1.75)	

3.5 Magnetic field radiation, UV radiation and cancer in shipyards

Electromagnetic emissions from laser, radar, communication, and microwave sources are examples of non-ionizing radiation. While shipyard workers, especially welders, can be exposed to extremely low frequency magnetic field and ultraviolet radiation (see Chapter 3.2.7) exposure to other frequencies is considered to be occasional. This is contrary to that of navy personnel who may be exposed continuously (e.g. to sonar radiation). Solar radiation has been categorised by IARC[81] as carcinogenic for skin and this is concluded to be due to the UV component; for low frequency EMF the evidence is not considered adequate by IARC[82].

For completeness the following section is a brief review of available knowledge on potential carcinogenicity of such exposures to provide a basis for assessing the occupational risk from this source in shipyards. Due to the rather general nature of much of the available data this section addresses the exposure to low frequency magnetic field and ultraviolet radiation (UVR).

3.5.1 Extremely low frequency magnetic field

Ahlbom (1988)[83] reviewed available data on magnetic fields and cancer, citing nine case-referent studies, conducted between 1979 and 1988. The limitations of the data in respect of exposure assessment and potential confounders are described and given balanced consideration. The author concludes that the evidence for an association between magnetic field exposure and cancer is not sufficient but that it is enough to justify further investigation. Savitz et al. (1989)[84] reviewed the methodology applied to epidemiological studies of EMF and cancer and concluded that the studies available at the time were failing to provide adequately quantified and relevant exposure information. The lack of understanding of mechanism and hence the role of potential confounders was identified as a major obstacle to resolving the role of EMF in human cancer.

McBride & Gallagher (1992)[85] provide an excellent summary of studies done up to that time including three studies published since the review of Ahlbom[83] above, all of which are case-control studies. Some serious deficiencies were noted in the early studies regarding lack of information on confounders and difficulties with exposure assessment. Overall the reviewer concludes that there is no clear association with childhood leukaemia but, despite small numbers, risk of childhood brain tumours appears to be consistently elevated. There is virtually no evidence for any effect of residential exposure to electromagnetic fields (EMF) on adult cancer risk. Occupational exposure to EMF linked to possible higher risk of leukaemia is mentioned briefly but not explored in depth. A brief editorial review by Newman (1992)[86] and a more detailed review by Knave (1994)[87] repeated some of the uncertainties still present in the research on this topic but did not add any additional data to the debate.

Savitz (1993)[88] provided one of the most comprehensive reviews of the relationship between cancer and EMF exposure and concludes that:

> "the associations reported between electrical occupations and leukaemia and brain cancer seem too consistent to be attributable to chance.....The critical question is whether that association is attributable to

> EMF exposure rather than to other workplace hazards or even some process of self-selection resulting in lifestyle factors which increase risk".

Improved exposure assessment is again a major recommendation of the review.

Theriault (1995)[89] reviewed studies relating occupational exposure to EMF with cancer and reported that pooled analysis of available data indicated an excess of leukaemia with a risk estimate of 1.18 (CI 95%; 1.09,1.29) and of acute myeloid leukaemia 1.46 (CI 95%; 1.27, 1.64). The methodology of this analysis and the studies included are not fully described. Some studies are reviewed which describe an association between brain cancer and potentially exposed workers however the exposure information is questioned. Three additional studies are reviewed which improve the exposure assessment by using individual exposure meters. The outcome remained inconclusive.

All previously published data were reviewed by IARC in 2002[82] and the assessment reported studies which had identified potential increased risk of leukaemia, brain tumours and male breast cancer in jobs with presumed exposure to electric and magnetic fields above average levels. It was concluded that there was no consistent finding across studies of an exposure-response relationship and no consistency in association with specific sub-types of leukaemia or brain tumour. There was inadequate evidence for any other cancer. The overall evaluation, based upon limited evidence for association of childhood leukaemia with exposure to extremely low-frequency magnetic fields, was that such fields are possibly carcinogenic to humans (Group 2B). There was inadequate evidence for static electric and magnetic fields.

A case-control study of male breast cancer is described by Demers et al. (1991)[90]. 227 cases which occurred over a 3-year period were compared with 300 randomly selected controls. Exposure was defined as ever or never having any employment in jobs associated with exposure to electromagnetic fields. An elevated risk was identified for any exposed job OR 1.8 (CI 95%; 1.0, 3.2). For certain job categories (electricians, telephone linesmen, and electric power workers) the risk was higher OR 6.0 (CI 95%; 1.7, 21.5). For radio and communications workers the risk was lower OR 2.9 (CI 95%; 0.8, 10.2) but showed some association with duration of employment.

Mack et al. (1991)[91] describes a case-control comparison of 272 US male glioma or meningioma cases with 272 controls. Employment for more than 10 years in occupations involving exposure to electrical or magnetic fields was not associated with an increase in meningioma risk but was associated with a non-significant increase in glioma risk 1.7 (CI 95%; 0.7, 4.4). For astrocytoma a significantly elevated risk 10.3 (CI 95%; 1.3, 90.8) was found for employment in occupations with exposure to electric and magnetic fields for more than 10 years. There was also a significant trend for increasing incidence with length of employment in such occupations.

Since difficulties with exposure assessment have been mentioned frequently as an obstacle to generating good quality information on the relationship between EMF exposure and cancer Armstrong et al. (1990)[92] set out to investigate potentially useful monitoring systems. It was concluded that both electric-field strength and magnetic field density should be monitored in any future studies.

Garland et al. (1990)[93] reported a case-control study with 102 cases of leukaemia among US Navy personnel. The scatter of cases across job descriptions is shown in Table 6 below:

Table 6

Leukaemia ratios(SIR) of Naval personnel aged 20-64 years between 1974 and 1984

Occupation	No. of cases	Person years	SIR (95% CI)
Aviation ordnance man	4	53943	2.9 (0.8, 7.3)
Electrician's mate	7	111944	2.5 (1.0, 5.1)
Boatswain's mate	5	78888	2.2 (0.7, 5.1)
Personnel man	3	52077	2.0 (0.4, 5.9)
Mess management specialist	4	86691	1.9 (0.5, 4.8)
Sonar technician	3	71602	1.7 (0.3, 4.9)
Storekeeper	3	61626	1.7 (0.4, 5.0)
Gunner's mate	3	69024	1.6 (0.3, 4.8)
Machinist's mate	7	235155	1.1 (0.5, 2.3)
Electronics technician	5	178555	1.1 (0.4, 2.6)
Radioman	4	133319	1.1 (0.3, 2.8)
Aviation structural mechanic	4	142165	1.1 (0.3, 2.7)
Hospital corpsman	5	177943	1.1 (0.3, 2.5)
Hull maintenance technician	3	111435	1.1 (0.2,3.1)
Seaman recruit	10	462341	1.1 (0.5, 2.0)
Airman recruit	3	169,175	0.9 (0.2, 2.6)
All Navy Occupations	102	4072502	

Only one occupation, electrician's mate, showed a significantly different incidence rate compared with the background navy population and this was of borderline significance. This study was included amongst those considered by IARC in the 2002 review[82].

3.5.2 UVR

The risks of skin cancer, particularly melanoma, from UV exposure are established in general (Dennis, 1997)[94]. Arc welding produces the full spectrum of UVR, including UVB. It is therefore likely that welders will be exposed to a greater risk of skin cancer than the rest of the population. Nevertheless, there has been minimal exploration to determine whether the UVR from arc welding is causing skin cancer.

Ocular melanoma may also be a risk for welders (Dixon & Dixon, 2004)[24] although eye protection is a normal part of the protective equipment and may reduce the risk. Although the hazard is present there is no record of this cancer being associated with welding-related UVR exposure in shipyard workers.

A review by Shah et al., (2005)[95] of 133 published reports on risk factors for uveal melanoma revealed 12 studies with sufficient information to calculate odds ratios (ORs) and standard errors for ultraviolet light exposure factors. For intermittent UV exposure, welding was found to be a significant risk factor (5 studies, 1137 cases; OR, 2.05 (CI 95%; 1.20-3.51). This meta-analysis

yielded inconsistent results associating UV light with development of uveal melanoma however there was evidence that welding may be a risk factor for this cancer.

A recent review of the relationship between UVR and ocular melanoma in welders has not yet been published (IARC 100D) but the conclusion that there was *sufficient evidence* for this relationship has been included in a presentation by Straif K. (2010)[6].

3.6 Conclusions regarding evidence for occupational risk of cancer in shipyards

After review of the available literature it is concluded that the risk of cancer in shipyard workers is dominated by the effects of asbestos (see section 3.2), where exposures can lead to either mesothelioma, larynx or lung cancer. It is not possible to calculate the direct relationship between exposure and risk due to the lack of exposure data for the period when maximum exposures were likely to be experienced, however some quantification of this risk is given in section 5.1.1.

Three out of 10 cohort studies of shipyard workers reviewed[22;37;42] showed an association between lung cancer and employment as a welder in shipyards. The studies of shipyard workers do not provide any further insight into whether lung cancer risk for welders is linked to any specific occupational exposure beyond asbestos. To assist conclusions cancer studies among welders in other industries are reviewed in more detail in Chapter 4.1.

Bladder cancer is the only other cancer which occasionally features at a significant excess, among the reported studies of shipyard workers but only in studies which have not adjusted data for smoking as a confounder. Since incidence does not appear to be associated with any specific occupation or exposure bladder cancer, as a general risk for shipyard workers, is not considered further. The study of Krstev (2007)[22] confirms that the association of woodworking with oral/naso-pharyngeal cancer should also be considered relevant for shipyards.

Considering the known effects of ionizing radiation and the risk of leukaemia and lung cancer the slightly increased rates seen at the highest levels of ionizing radiation exposure found in some occupations in specific shipyards cannot be ignored, but at lower exposures the effect is not measurable. The quantitative aspects of this risk in those shipyards handling nuclear powered vessels will be explored in more detail in Section 5.2.

Although it has been proposed by many reviewers that EMF exposure is associated with an increased risk of leukaemia or brain cancer there is no evidence for considering this a relevant or specific risk for shipyards. This potential association is not considered further in this review.

The association of UVR exposure with ocular melanoma is of particular relevance to welders and is considered to be a potential risk for shipyard workers.

[6] http://www.collegiumramazzini.org/download/STRAIF10.pdf

Due to lack of available occupation and exposure data, many of the studies of shipyard workers are limited in their ability to detect specific occupational risks. For this reason those studies do not fully reflect known risks for some of the occupations present in shipyards. For completeness each of those occupations is given more detailed consideration in Chapter 4, drawing on data from non-shipyard exposures, where such data are available.

4. CANCER ASSOCIATED WITH SPECIFIC OCCUPATIONAL EXPOSURES

4.1 Welding

The risks associated with the occupation of welder derive not only from exposures resulting from the specific task of welding but additionally from exposures derived from other activities within the working place. In shipyards all workers employed prior to the 1980s have had a significant but undefined level of exposure to asbestos. The background risk from the asbestos exposure will influence the effects of other exposures including welding fume and often confounds the detection of welding-specific risks. The following section is a summary of available data regarding cancer consequences of the occupational exposure of welders, particularly, but not exclusively to welding fume. The specific risks of Chromium and Nickel, as components of fume, are also given consideration.

4.1.1 Reviews

IARC reviewed 23 studies in 1990[96] and on the basis of limited evidence of carcinogenicity for humans and inadequate data in animals concluded that welding fumes were *possibly carcinogenic* to humans (2B). A NIOSH review[7] of the occupational risks for welders, prepared in 1988 came to a similar conclusion to IARC, that welders may have a 40% increase in the relative risk of developing lung cancer as a result of their work experience. The possible confounding effects of smoking habit and exposure to other occupational carcinogens are mentioned. The possible specific risks for workers welding stainless steel, and relevance of fumes containing chromium and nickel are also mentioned.

Stern (1981)[97] suggested that excess of lung cancer in welders might derive from exposure to substances such as nickel and Cr (VI) but no data were presented to support this conjecture. Stern (1982[98]; 1983[99]) reviewed all studies available at the time on welding and lung cancer, many of which were also part of the later IARC review and concluded that "after excluding effects for shipyard employment and smoking there still appears to be an irreducible excess risk for lung cancer for general welding populations"..."amounting to an excess risk of approximately 30% above that of the non-welding population". It was postulated that the excess risk might be mostly due to the effects of Cr (VI) exposure in stainless steel welders.

Gallagher & Threlfall (1983)[100] analysed all death certificates for British Colombia between 1950 and 1978 drawing out a population of 10,036 metal workers sub-divided into various occupational categories, one of which was Welders. This report[100] was followed up by Gallagher et al. (1991)[101] with a brief but more detailed analysis of lung cancer rates in metal workers using a slightly extended data-set spanning the period 1950-1984. The PMR were analysed for all cancers and separately for social class in an attempt to compensate for smoking bias. The specific associated risks of lung cancer and Hodgkin's disease were reconfirmed by this publication but similar reservations about the lack of direct knowledge about smoking history still apply.

Langard & Stern (1984)[102] reviewed the potential hazard of Nickel in welding fumes, although confirming the exposure of some groups of welders to Nickel and Chromium as well as other potentially carcinogenic substances, the authors could not identify any evidence to support a specific risk of cancer associated with those exposures. Stern et al. (1986)[103] in a presentation to an International Conference concluded that there was considerable evidence of a moderate increase in lung cancer risk among this occupation, but there was a possibility of the excess being due to cigarette smoking, asbestos exposure or to another specific risk.

A dissertation by Sjögren (1985)[104] included a useful background description of welding and a brief report of a review of the data from a cohort of stainless steel welders published in 1980[105] and summarised in Table 7. The reanalysis failed to identify any occupationally related cancer in the cohort.

A review by Moulin et al. (1991)[106] of 21 case-control studies and 27 cohort studies found overall a relative risk of lung cancer of 1.40 for all welders but lack of data on smoking habits in many studies and the unknown contribution of asbestos makes it impossible from these data to reach a final conclusion on the causative relationship between welding and lung cancer. The similar timing to the IARC review and thus similar base of data and conclusions reduces the independent value of this review.

Apart from those publications mentioned above the individual studies which predate the IARC opinion are not reviewed in depth, but all papers published before 1990 and retrieved in the literature search are summarised in Table 7. Papers published since 1990 are summarised in Table 8 and are also described in more detail in the following text.

On the basis of the assessment of existing data in all the reviews summarised above it is concluded that respiratory cancer is the only cancer showing some potential association with occupational exposures related to welding thus all remaining discussion about this occupation will focus on that end-point.

Table 7

Data on cancer rates of welders published prior to IARC review 1990

Reference, (Location)	Cohort / study characteristics: Numbers	Confounders Included in analysis and exposure data	No. of deaths/cases	Exposure categories	Obs/exp or cases/controls	RR, OR, SMR or SIR (95% CI)	Comments
Cohort studies							
Sjögren (1980)[105] (8 Swedish companies)	234 welders with at least 5 years SS welding experience 1950-1965	Exposure was not measured. Inadequate control for smoking and asbestos exposure.	17	All cohort	3/0.68	Not given	**NB**: 1987 paper comments that the data in this paper were erroneously presented.
Beaumont & Weiss (1981)[107] (Shipyard Seattle, USA)	3247 Welders 5432 non-welders from same location	No specific account taken of other risk factors such as smoking or specific exposure to asbestos, Cr or Ni	529 deaths 1950-1976	Whole cohort (internal analysis) 20 years from 1st employment	50/37.95 39/22.38	RR 1.32 (p=0.06) RR 1.74 (p<0.001)	Expected numbers based on US general figures
Sjögren & Hogstedt (1982)[108] (Swedish Census)	26 000 welders in the Swedish National census (1960), reviewed in 1970.	The letter describes a nested case-control study of welders and gas-cutters and separately stainless steel welders.		Welders & Gas-cutters: Trachea, bronchi & lung cancer Mesothelioma Stainless steel welders: Lung cancer	 96/66.64 4/1.17 3/0.68	 OR 1.44 (p< 0.001) OR 3.43 (p 0.03) OR 4.4 (p< 0.03)	Brief report in a letter to the editor Mesothelioma incidence confirms the exposure to asbestos.
Gallagher & Threlfall (1983)[100] (British Colombia)	10 036 metal workers from all deaths 1950-1978	No information on smoking	1002 Welders	Lung Cancer Hodgkin's Disease All cancers	74 9 207	PMR 145 (115, 183) PMR 242 (110, 460) PMR 114 (99, 132)	Based on death certificates only.

Table 7

Data on cancer rates of welders published prior to IARC review 1990

Reference, (Location)	Cohort / study characteristics			Exposure categories	Obs/exp or cases/controls	RR, OR, SMR or SIR (95% CI)	Comments
	Numbers	Confounders Included in analysis and exposure data	No. of deaths/cases				
Becker et al. (1985)[109] (25 factories in Germany)	1221 SS Welders 1694 turners	Smoking rates were factored into calculation	77	≤9 years 10-19 years 20-29 years ≥30 years	0/1.0 1/2.3 4/2.5 1/0.6	 SMR 0.433 SMR 1.63 SMR 1.76	2.3% lost to follow-up.
Newhouse et al. (1985)[41] (NE England Shipyard)	1027 Welders	No information on smoking habits or on asbestos exposure.	195		26/22.9	SMR 1.13 (0.8, 1.57)	More data in Table 5
Sjögren. (1987)[110]	Two cohorts of SS welders:	high exposure (234) low exposure (208).	32 47	High exposure Low Exposure High exposure (234) versus Low exposure (208)	5/2 1/3	SMR 2.49 (0.80, 5.81) SMR 0.33 (0, 1.84) RR 7.01 (1.32, 37.3)	Elevated RR attributed to higher Cr exposure but too many other variables are present.
Tola et al. (1988)[111] (5 Shipyards and 4 machine shops in Finland)	Total 12 693 (7775:4918)Shipyard:Machine shop Welders (1308:381) Platers (3274:1034) Machinists (2585:3418) Pipe-fitters (608:85)	The smoking habits were not known but were assumed to be similar to the general population. Asbestos exposure was thought potentially responsible for some excess cancers but could not totally explain all of the excess seen.		Shipyard workers Welders Platers Machinists Pipe fitters Machine shop workers Welders Platers Machinists Pipe fitters	227/192.1 27/23.5 103/88.5 87/77.5 23/15 110/118.8 14/9.9 34/36.1 67/79.7 2/3.8	SIR 1.18 SIR 1.15 SIR 1.162 SIR 1.12 SIR 1.54 SIR 0.93 SIR 1.42 SIR 0.94 SIR 0.84 SIR 0.53	No increase in risk was seen with increasing time of follow-up.

Table 7

Data on cancer rates of welders published prior to IARC review 1990

Reference, (Location)	Cohort / study characteristics: Numbers	Confounders Included in analysis and exposure data	No. of deaths/cases	Exposure categories	Obs/exp or cases/controls	RR, OR, SMR or SIR (95% CI)	Comments
Case-control studies							
Olsen *et al*. (1984)[112] (Denmark)	Case-control study (larynx cancer).			All (matched controls) Sub-glottle cancer (unmatched controls) (matched controls)	271/971 11/971 11/971	RR 1.6 (1.0, 2.4) RR 6.3 (1.8, 21.6) RR 8.1 (1.5, 43.3)	The RR appeared to be greater for Glottle and supra-glottle cancer in smokers.
Silverstein *et al*. (1985)[113] (Factory, Michigan USA)	94 deaths from UAW members employed 1966-1982.	Smoking habits were not known. Only 83 with full work histories		All Welder/Millwright	10/4.75 3/1	SPMR 2.2 (1.18, 3.76)	US White males used as the reference population. Only 28 cancer cases in total.
Hull *et al*. (1989)[114] (Los Angeles County)	128 cases of pulmonary malignancy among white welders and 177 control subjects	Analysis of specific exposures was limited to 85 cases and 74 controls due to concerns about reliability of data. Cases smoked more than controls (98% vs 88%) but unadjusted data are reported.	(only 90 cases and 116 controls were successfully interviewed)	Ever versus never exposed Ever versus never exposed (10 yr) Manual metal arc welding Gas-shielded arc welding Stainless steel welding High-alloy steel welding Mild steel welding Manual metal arc welding SS Confined space welding Asbestos exposure Fibreglass exposure	37/34 37/33 30/24 38/35 34/31 17/21 56/41 61/49 38/42 31/22 22/11	OR 1.7 (0.9, 3.1) OR 1.8 (0.9, 3.2)* OR 1.1 (0.6, 2.7) OR 0.9 (0.5, 1.8) OR 0.9 (0.5, 1.8) OR 0.6 (0.3, 1.4) OR 1.6 (0.8, 3.1) OR 1.3 (0.6, 2.3) OR 0.6 (0.3, 1.2) OR 1.4 (0.7, 2.8) OR 2.0 (0.8, 5.2) *P=0.04 (1,sided fisher's)	Claimed that the results for ten-year latency on "ever exposed" is significant but the lack of adjustment for smoking .and greater frequency in the cases confounds this analysis

4.1.2 Study data since the review by IARC

The largest study available on welders was conducted under the auspices of IARC and reported by Simonato et al. (1991)[115]. The study extended over 135 companies in 9 countries with a total cohort of 12 119. In total 1027 subjects were excluded from analysis resulting in a population of 11 092 on which all the data analysis was based. The different national inputs were derived from cohorts studied at different points in time and with different employment profiles but roughly spanning the period 1960 to 1984. The total number of deaths during the period studied was 1093.

For each subject a cumulative dose was computed based on a consistent algorithm taking account of type of metal welded and technological changes over time. Exposure to other variables such as asbestos, α-radiation or electromagnetic fields could not be estimated. Expected incidence rates were computed using the relevant national rates. Although higher rates of lung cancer were found in welders there was no detected association with type of welding or exposure. The evidence for increasing risk with increasing duration of exposure and employment is very limited. There was some indication of an excess of lung cancer in mild-steel welders, particularly 20 years or more since first employment.

The confounding effects of asbestos exposure could not be considered since there were no data on this exposure; however the occurrence of 5 cases of mesothelioma in the cohort suggests that there was asbestos exposure in the workforce. Smoking habit was not included as an element in the analysis since this information was not available for all members of the cohort. In a separate analysis, using some sub-sets of the cohort where smoking data were available, there was no suggestion of a major difference in smoking habit between the welders and the general population. It is considered unlikely that smoking alone can explain the excess of lung cancer in welders however asbestos exposure cannot be ruled out as a contributor to the excess cancer risk seen. The lack of documented exposure data for asbestos means that this contribution cannot be quantified.

An attempt to improve the analysis of welding exposure was described by Gerin et al. (1993)[116] in the same cohort of welders, taking account of the exposure to Chromium (both total and Cr VI) and Nickel. The analysis showed an association with Ni exposure (0.1-0.5 mg years/m^3 but no such association at higher exposure. Any firm conclusion from the study is limited by the small numbers of exposed cases.

In a study of a cohort of 4571 shipyard workers reported by Danielsen et al. (1993)[42] there was an excess of lung cancers among welders compared both with the general Norwegian population and with other shipyard workers (Table 8).

In a cohort studied by Moulin et al. (1993)[117] welders working with non-ferrous or mild-steel for more than 20 years showed a significant increase of broncho-pulmonary cancer (SMR 3.24 CI 95%; 1.05, 7.55). This study reproduces the observation of greatest effect in mild-steel welders reported by Simonato et al. (1991)[115].

Hansen et al. (1996)[118] identified significant excess lung cancer rates among all welders but there is no evidence of increasing rates among those with the greatest duration of exposure (Table 7). There also appears to be an increased risk among those who have never been involved with welding which suggests a cause other than direct exposure to welding fumes. Thus while the data are indicative of occupationally-related causes they are not sufficient to conclude on the relationship between welding and lung cancer rates.

A study of welders employed at a US government depot reported by de Silva et al. (1999)[119] was based on 199 employees, many with incomplete records. Within the limits of the study there was no evidence for any effects of welding on cancer rates (Table 8). Danielsen et al. (2000)[43] report an investigation of cancer mortality rates in a group of Norwegian shipyard workers which concentrated on confounding variables related to lung cancer incidence in shipyard workers (Table 8). No significant effect was seen on lung cancer rates in any of the occupations. Although there was a slight excess of lung cancer in welders with >15 years employment this was not significant. Four mesothelioma cases in the group indicated some history of exposure to asbestos.

A study of stainless steel welders reported by Becker et al. (1991)[120] (Table 8) showed a slight excess of bladder and lung cancer compared with the normal population, but not when compared with non-welding workers. The occurrence of three mesothelioma cases in this data set implies a potential effect of asbestos on the outcome of the study thus no definite association between welding and tumour incidence can be concluded. Further follow-up of the same cohort to 1995 was reported by Becker et al. (1999)[121] and showed similar results to those reported earlier but based upon 268 deaths among the welders and 446 in the comparison group. The authors conclude that any excess of cancers in this study is likely to be predominantly due to asbestos and that the results do not indicate an increased cancer risk attributable to welding.

Cancer incidence was studied in Norwegian boiler welders, including Stainless steel welders (Danielsen et al., 1996)[122]. There was no significant excess of lung cancer in this group; however kidney cancer did occur more frequently than expected, but the rate for both cancers is rather borderline on significance. There were no specific differences between the stainless steel welders and the rest of the cohort (Table 8). The occurrence of 3 pleural mesotheliomas in the cohort is suggestive of some asbestos exposure and this, combined with lack of allowance for smoking differences, is sufficient to raise serious questions over the results.

An analysis of lung cancer deaths from a large cohort (Lauritsen & Hansen, 1996)[123] showed a slight excess in welders but no correlation with duration of exposure. The lack of information on asbestos exposure means that this cannot be excluded as a cause of the difference seen.

Moulin (1997)[124] prepared a meta-analysis of all studies on welding and cancer reported between 1954 and 1994, comprising 18 case-referent and 31 cohort studies. Thirteen studies were excluded from analysis as they were in some way duplicates, leaving a total of 36 studies for the analysis (16 case-referent; 20 cohort). The overall conclusion supports that of IARC with a general increased relative risk of lung cancer in welders of 30 to 40%. It is concluded that lung cancer risk cannot be specifically attributed to stainless steel welding and that smoking could be responsible for part of the excess seen. An additional conclusion that asbestos is likely to be a

causative factor for the lung cancer excess observed among welders is an important observation, particularly as asbestos exposure is very poorly documented in many of the studies.

Steenland (2002)[125] reported a follow-up to an earlier study of a cohort of mild-steel welders at three US manufacturing plants. These data are particularly interesting since it is claimed that none of the welders had any exposure to asbestos thus this potential confounder was absent. The only cancer showing an elevated incidence in welders compared with the general US population was lung cancer. The lung cancer rate was not however significantly different between the welders and a control group of non-welders (4286) employed at the same plants. The analysis is based on 108 deaths from lung cancer (see Table 8). The excess of lung cancer is not significant and there is no indication of a relationship with exposure. It is stated that smoking differences between welders and non-welders could account for at least part of the difference seen.

A review by Antonini et al. (2003)[126] of pulmonary effects of welding fumes cited a number of epidemiological studies which are reported here in full and confirmed that no additional animal data had been developed since the original IARC opinion. A second contemporary review by Antonini (2003)[127] repeated the comment that the available data are confounded by inaccurate exposure assessments and inadequate information on other factors such as asbestos exposure and smoking habits.

Siew et al. (2008)[128] studied the relationship between lung cancer and exposure to welding fumes and to iron. Despite the large population the numbers of cases in each category of analysis were relatively small thus it was not feasible to separate the effects of welding fumes and iron but the indications of an increased risk of lung cancer in those exposed is consistent with other studies. An analysis of rates in shipyard welders showed no additional risk compared with other welders but numbers were too small for further conclusions.

A meta-analysis of five studies with Welders was reported by Sjögren et al. (1994)[129] and identified an increased risk of lung cancer RR 1.94 (CI 95%; 1.28, 2.93). The analysis confirms the trends observed in a range of studies but could not identify any specific causative agent. The lack of control for asbestos in many of the studies leaves this as the prime suspect for causative agent of lung cancer among welders.

Table 8

Data on cancer rates of welders reported since 1990

Reference, (Location)	Cohort / study characteristics			Exposure categories	Obs/exp or cases/controls	RR, OR, SIR or SMR (95% CI)	Comments
	Numbers	Confounders Included in analysis and exposure data	No. of deaths/cases				
Cohort Studies							
Simonato et al. (1991)[115] (9 countries/135 companies , IARC study)	11 092	No allowance for smoking.	1093	All cohort	116/86.81	SMR 1.34 (1.10, 1.60)	Generally no relation between duration of exposure and rate of lung cancer. No other significant exposure-related cancers.
				Shipyard welders	36/28.62	SMR 1.26 (0.88, 1.74)	
				Mild steel welders	40/22.42	SMR 1.78 (1.27, 2.43)	
				Stainless steel ever welders	39/30.52	SMR 1.28 (0.91, 1.75)	
				Predominantly Stainless steel welders	20/16.25	SMR 1.23 (0.75, 1.90)	
Becker et al. (1991)[120] (25 factories in Germany)	1221 Cr and Ni exposed welders Compared with 1694 turners	Adjusted for smoking	153	Lung cancer	14/12.4	SMR 1.13 (0.67, 1.91)	The mortality rates were compared with those of the normal German population. Comparing the two groups for total lung cancer incidence there was a slight excess in the welders (RR = 1.2 95% CI 0.6, 2.2)
				Mesothelioma	3/0.3	SMR 9.61 (3.10, 9.99)	
			288	Bladder	4/1.3	SMR 3.04 (1.14, 8.10)	
				Lung cancer (smokers)	13/7.3	SMR 1.79 (1.04, 3.08)	
				Mesothelioma (smokers)	2/0.2	SMR 10.98 (2.75, >9.99)	
				Lung cancer by time since first exp.			
				≤ 9 yr	0/1.0	-	
				10-19 yr	2/3.6	SMR 0.56 (0.14, 2.24)	
				20-29 yr	7/4.9	SMR 1.42 (0.68, 2.99)	
				≥ 30 yr	5/2.9	SMR 1.72 (0.72, 4.14)	
Gérin et al. (1993)[116] (135 companies in nine EU member states)	11 092 male welders	Attempted to assess exposure to four different welding fume components (Total, Cr (VI), Total Cr, Ni).	Not given	Cr VI < 0.05 mg.years/m^3	0/0.29	SMR 0 (0, 12.72)	Analysis is based on welders with at least 5 years of employment and 20 years since first exposure.
				Cr VI 0.05-0.5 mg.years/m^3	7/5.39	SMR 1.3 (0.52, 2.68)	
				Cr VI 0.5-1.5 mg.years/m^3	9/4.67	SMR 1.93 (0.88, 3.66)	
				CR VI ≥1.5 mg.years/m^3	5/3.55	SMR 1.41 (0.46, 3.29)	
				Ni < 0.1 mg.years/m^3	0/0.72	SMR 0 (0, 5.12)	
					17/9.51	SMR 1.79 (1.04, 2.86)	
				Ni 0.1-0.5 mg.years/m^3	4/3.67	SMR 1.09 (0.3, 2.79)	
				Ni ≥ 0.5 mg.years/m^3			
Danielsen et al. (1993)[42] (Norwegian shipyards)	4571 shipyard workers including 623 welders. First employed 1940-1979. Monitored up to 1989	Limited data were available on occupation, smoking habit and exposure. Smoking was more prevalent among welders than the general population but similar to the rest of the shipyard cohort.	1078	High exposure welders (255)	6/1.6	SIR 3.75 (1.38, 8.19)	The lung cancer figures are based on groups who had started work at least 15 years previously.
				Very High exposure welders (207)	4/1	SIR 4.00 (1.10, 10.20)	
				Burners (45)	3/0.8	SIR 3.75 (0.75, 11.00)	
				Whole cohort		SIR 1.40 (1.08, 1.79)	
				Welders compared with other shipyard workers		RR 3.75 (1.38, 8.19)	
Moulin et al. (1993)[117]	2721 welders and 6683	Smoking habits were known for >86% of both	730	Total			Cause of death ascertained for 98%
				Part-time welders	3/2.639	SMR 1.14 (0.24, 3.33)	

Table 8

Data on cancer rates of welders reported since 1990

Reference, (Location)	Cohort / study characteristics			Exposure categories	Obs/exp or cases/controls	RR, OR, SIR or SMR (95% CI)	Comments
	Numbers	Confounders Included in analysis and exposure data	No. of deaths/cases				
(13 French factories including shipyards)	manual workers. Mortality data 1975-1988	populations. The smoking rates were found to be so similar between the different groups that it was considered that there was no likelihood of significant bias. Due to potential confounding by asbestos exposure occurring in shipyards the data for these locations was analysed separately.	Welders203 Manual 527	Mild steel welders Ever SS welders Predominantly Cr VI ≥20 year exposure Low exposure welders Mild steel & non-ferrous welding Stainless-steel welders Welders exposed to Cr (VI)	9/5.65 3/3.26 2/1.95 3/0.96 5/1.54 0/0.47 0/0.23	SMR 1.59 (0.73, 3.02) SMR 0.92 (0.19, 2.69) SMR 1.03 (0.12, 3.71) SMR 3.11 (0.64, 9.10) SMR 3.24 (1.05, 7.55) SMR 0.00 (0.00, 7.82) SMR 0.00 (0.00, 15.85)	of individuals. All figures are related to duration of exposure with a 5-year lag.
Hansen et al. (1996)[118] (79 Danish welding companies)	10 059 male metal workers	The analysis has taken account of information on smoking and asbestos exposure but is reliant on colleague or family questionnaire for these details for those who had died. Asbestos exposure data was missing from 1/3 of responses.	812	Total cohort (10,059) Ever employed as a welder (75,592) Non-welding metal-workers (1,675)	105/69.95 51/36.84 45/26.68	SIR 1.51 (1.24, 1.83) SIR 1.38 (1.03, 1.81) SIR 1.69 (1.23, 2.26)	Expected incidences based on the Danish National statistics.
Danielsen et al. (1996)[122] (Norwegian Boiler welders)	2957 boiler welders Including a sub-cohort of 606 SS welders	Details of actual occupation and exposures were not confirmed; there was also no information on smoking habits	625	Lung cancer Kidney cancer	50/37.5 19/10.7	SIR 1.33 (0.99, 1.76) SIR 1.78 (1.07, 2.78)	3 cases of mesothelioma in the group of welder deaths
Becker (1999)[121] (25 factories in Germany)	1213 welders 1688 turners		274 448	All malignant neoplasms Mesothelioma	84/80.3 7/0.6	SMR 1.05 (0.84, 1.30) SMR 11.79 (4.73, 24.31)	Any excess cancer was concluded to be due to asbestos exposure.
de Silva et al. (1999)[119] (US Military depot)	199 welders employed before 1980 and not ended before 1966.	No correction for smoking or asbestos exposure	17	Welders all categories		SMR 1.10 (0.30, 2.81)	Depot was operational since early 1940s. Used geographical Information system approach to building a more complete data set.

Table 8

Data on cancer rates of welders reported since 1990

Reference, (Location)	Cohort / study characteristics			Exposure categories	Obs/exp or cases/controls	RR, OR, SIR or SMR (95% CI)	Comments
	Numbers	Confounders Included in analysis and exposure data	No. of deaths/cases				
Danielsen et al. (2000)[43] (Norwegian shipyard)	4480 shipyard workers including 861 welders. Employed 1945-1991	Smoking habit and previous employment was considered in analysis. Approx 10% excess of smokers in the welders.	801	All cohort - all cancer All cohort - lung cancer Welders - lung cancer Analysis by duration of employment ≥15 years employment.	441 45/51.3 9/7.1	SIR 1.06 (0.96, 1.17) SIR 0.88 (0.64, 1.17) SIR 1.27 (0.58, 2.42) no association with cancer risk RR 1.9 (0.67, 5.38)	4 cases of mesothelioma; none among welders.
Steenland (2002)[125] US heavy manufacturing plant	4459 mild steel welders and 4286 non-welders from the same plants	Welders had not been exposed to asbestos.	108	All vs. US population All vs. non-welders Duration of exposure vs. non-welders 2-5 years 5-10 years 10-15 years 15-20 years >20 years		SMR 1.46 (1.20, 1.76) SMR 1.222 (0.93, 1.59) SMR 1.26 (0.71, 2.21) SMR 0.88 (0.47, 1.66) SMR 1.47 (0.75, 2.86) SMR 1.22 (0.63, 2.38) SMR 1.06 (0.59, 1.90)	
Registry studies							
Siew et al. (2008)[128] (Finnish registry)	30 137 Lung cancer cases 1971-1995	Risk estimates were adjusted for smoking, socio-economic status and exposure to asbestos and silica dust.	26 24 102	welding fumes exposure (iron exposure ≥50 mg/m^3-years) ≥100 mg/m^3-years ≥200 mg/m^3-years Iron exposure (welding fume exposure ≥200 mg/m^3-years) ≥10 mg/m^3-years ≥50 mg/m^3-years Welder shipyard Welder building Welder NEC		 RR 1.33 (0.50, 3.55) RR 1.54 (1.17, 2.04) RR 1.25 (0.95, 1.65) RR 1.23 0.95, 1.61) SIR 1.05 (0.69, 1.55) SIR 1.31 (0.84, 1.95) SIR 1.39 (1.14, 1.69)	Exposure estimates for fumes and iron were based upon the census occupation in 1970.
Case-control Studies							
Lauritsen & Hansen (1996)[123] (79 Danish welding companies)	94 deaths from lung cancer from a cohort of 8372 metal workers compared with 439 referents	Although analysis is said to have compensated for smoking in a logistic regression model the data for the referents is not reported. Data on asbestos exposure was unavailable for many in the sample thus confounding effects of this could not be analysed.		Welding ever (46) Exposed: 1,5yr (8) 6-10yr (7) 11-15yr (10) 16-20yr (7) >20yr (14)		OR 1.7 (1.0, 2.8) OR 1.7 (0.6, 4.1) OR 2.1 (0.7, 5.7) OR 3.2 (1.2, 7.9) OR 1.5 (0.5, 3.9) OR 1.2 (0.6, 2.5)	

Table 8

Data on cancer rates of welders reported since 1990

Reference, (Location)	Cohort / study characteristics			Exposure categories	Obs/exp or cases/controls	RR, OR, SIR or SMR (95% CI)	Comments
	Numbers	Confounders Included in analysis and exposure data	No. of deaths/cases				
Meta-analyses							
Sjögren et al.(1994)[129] (Meta-analysis of SS welding fumes and lung cancer)	Lung cancer rates from 5 studies were analysed	Meta-analysis is based on a simple pooled estimate of relative risk. (3 case-referent and two cohort studies)		Canada (C-R) (1984) Denmark (C-R) (1996)[118] France (Cohort) (1993)[117] Norway (C-R) (1986) Sweden (Cohort) (1987)[110]		OR 3.3 (1.2, 9.2 OR 1.57 (0.85, 2.89) SMR 0.97 (0.12, 3.51) OR 2.56 (0.85, 7.54) SMR 2.04 (0.66, 4.76) Pooled RR 1.94 (1.28, 2.93)	Three studies rejected for various reasons but the quality of data used is variable
Moulin (1997)[124] (meta analysis of 36 studies)				All or unspecified welding categories Population-based studies (7) Case-referent studies (9) Cohort studies (3) Shipyard welding Case-referent studies (6) Cohort studies (8) Non-shipyard welding Case-referent studies (1) Cohort studies (6) Mild steel welding Case-referent studies (2) Cohort studies (2) Stainless steel welding Case-referent studies (2) Cohort studies (5)		RR 1.38 (1.29, 1.48) RR 1.39 (1.28, 1.51) RR 1.72 (1.36, 2.18) RR 1.27 (1.22, 1.55) RR 1.30 (1.14, 1.48) RR 1.16 (0.92, 1.47) RR 1.36 (1.17, 1.60) RR 1.35 (1.15, 1.58) RR 3.8 (1.4, 10.7) RR 1.31 (1.12, 1.54) RR 1.50 (1.18, 1.91) RR 1.56 (0.82, 2.99) RR 1.49 (1.15, 1.93) RR1.50 (1.10, 2.05) RR 2.00 (1.22, 3.28) RR 1.23 (0.82, 1.85)	All analyses are for lung cancer rates.

4.1.3 Nickel & Chromium

Gérin et al (1985)[130] published an analysis of data on the occupation of males in Montreal aged between 35 and 70 and diagnosed with one of 14 types of cancer. The paper is published in French with an English abstract. Results in 1982 on 1500 work histories for nickel exposure identified a significant association between nickel and/or chromium exposure and lung cancer (RR 3.1 CI 95%; 1.9, 5.0).

An assessment of the carcinogenicity of Chromium was summarised by IARC in 1987[131] and the evidence for association with lung cancer was regarded as sufficient for Cr (VI) (hexavalent chromium) compounds. For chromium metal and trivalent salts the evidence for an association with cancer was inadequate. The carcinogenicity of nickel and nickel compounds was reviewed by Sunderman (1973)[132] and IARC in 1987[133] with the conclusion of sufficient evidence for association with cancers of nasal cavity, lung and possibly larynx. The specific nickel compounds responsible could not be identified but the strongest evidence came from exposure during nickel refining and smelting. Nickel (sub) sulphides and oxides were specifically mentioned as potential candidates for the causative agent. However a review by Longstaff et al. (1984)[134] argued that there was sufficient evidence to support the lack of carcinogenicity of Nickel and Nickel Oxide and that the IARC classification should be modified.

Hayes (1988)[135] reviewed the epidemiology of chromium exposure and occupational cancer and identified that Cr (VI) is the main form of chromium released during the use of coated electrodes when welding stainless steel. However he concluded that the data available at that time were inadequate to support any association between stainless steel welding and lung cancer.

Langård (1993)[136] reviewed exposure data regarding soluble and insoluble forms of Cr (VI) and concluded that the difference in carcinogenic potency of different exposures to Cr (VI) may be related to persistence. This tends to confirm that evidence of exposure alone cannot be taken as sufficient grounds for assuming a risk. Langård (1994)[137] reviewed the background evidence for nickel-related cancer in welders and concluded that the only cancer potentially related with this exposure was lung cancer and that available data were often confounded by lack of information on smoking and asbestos exposure.

Potential carcinogenic effects of Cr and Ni fumes from welding were studied by Popp et al. (1991)[138] using *in vitro* assessment of Sister Chromatid exchange (SCE) and DNA strand breaks in lymphocytes from exposed workers. The study was based upon 39 German welders compared with 18 controls. Individual urine measurement of Cr and Ni was made along with assessment of SCE and DNA strand breakage and elution rate. Exposure levels were low although urine levels of Cr were still above the recommended threshold level of 40 µg/L. SCE levels were significantly lower in welders than controls but raised for smokers in both groups. Elution rate of DNA was regarded as a measure of protein cross-linking and was correlated with urine Cr measurements. Strand breakage was reduced in the exposed group. Overall these data provide some evidence for the exposure to Chromium but not the expected confirmation of genotoxicity.

Jakobsson et al. (1997)[139] report on a follow-up of a cohort of 727 Swedish stainless steel grinders, burnishers and welders employed for at least 12 months between 1927 and 1981. Exposure was to dusts containing Cr and Ni but no cutting fluids. Reference cohorts drawn from

other industries with no dust exposure were included in some analyses while expected rates for cancer were derived from local county rates for each cohort. In total 292 deaths occurred in the cohort. The only cancer rate to show an overall excess in the exposed cohort was prostate (SIR 1.7 CI 95%; 1.2, 2.4). Although overall rates for colon cancer were not significantly different from background, analysis by calendar year of first employment showed a marked excess of sigmoid cancer for those first employed between 1927 and 1942 (SIR 10 CI 95%; 2.7, 26) compared with those employed later. This difference in cancer rate cannot be attributed to any specific causative agent or exposure.

Following an investigation of GI tract cancer rates and possible effects of hexavalent chromium by literature review and meta-analysis Gatto et al. (2010)[140] concluded that there was no evidence for increased GI cancer risk in Cr (VI) exposed workers, including welders.

4.1.4 Welding - Conclusions

The only cancer to be mentioned consistently in studies of welding is cancer of the lung, thus this is the only potential association considered. The risk ratios are frequently in excess of 1 but less than 2; in many recent studies the results are often not significant, with the lower confidence limit being below 1.

Attempts to identify causative agents have raised suspicion of CR (VI) and Ni exposure in SS welders but studies have consistently demonstrated that groups exposed to Cr (VI) and/or Nickel do not have any greater risk of lung cancer than other welders. Thus stainless steel welders cannot be considered a specific at-risk group.

UVR has recently become recognised as a specific hazard for welders with risk of both skin and ocular cancer. However evidence for a significant risk among shipyard workers has not been found in the papers reviewed.

The exposure of many welders in shipyards to asbestos is frequently confirmed by the occurrence of an excess of mesothelioma; they have worked in premises where asbestos has been used and also used asbestos-containing materials. Additionally the role of smoking in the origin of the excess of cancers observed has not been entirely eliminated from many analyses. The known potential for the combination of smoking and asbestos exposure to cause a higher lung cancer rate than either alone has not featured in any of the analyses, due to inadequate information on both factors, but could provide one explanation of the apparent excess rates. Due to the frequency of observation of a small excess risk the association of excess lung cancer and working as a welder can be confirmed but without any conclusion concerning the causative agent.

4.2 Cutting oils and fluids and cancer

One of the potential health issues recognised for those grinding or machining metal plates relates to the exposure to cutting oils/metal-working fluids (MWF) used to lubricate and assist the cutting and grinding process. There are no study reports available for this exposure in shipyards thus the following review has tried to consider data from other sectors which might have some relevance to shipyard working. IARC (1984[16], 1987[86]) considered unrefined mineral oils to be carcinogenic for humans, based upon epidemiological evidence of association with scrotal cancer and squamous cell carcinoma of the skin, plus limited evidence of links to lung and alimentary tract cancer. A possible excess of bladder cancer was noted after exposure to cutting oils containing aromatic amines.

A concern about potential carcinogenicity of cutting oils followed publication by NIOSH[141] of analytical results finding low levels of N-nitrosodiethanolamine in samples of commercial cutting fluids. Garry et al. (1986)[142] studied the genotoxicity of some water-soluble and non-water-soluble cutting fluids and identified mutagenic potential in the bacterial reverse mutation assay for several water-soluble fluids. Analysis of these fluids for nitrosamines identified high levels of N-nitrosodiethanolamine and levels of other nitrosamines (dimethyl, diethyl and dibutyl) in the region of 1 ppm.

The health effects of oil mists was reviewed by Mackerer (1989)[143] concluding at the time that there was no convincing evidence that cutting fluid exposure had produced cancer in any organ other than skin, despite the potential carcinogenicity of PAH (Polycyclic Aromatic Hydrocarbon) and nitrosamine contaminants. The PAH content of oils was considered to be the main explanation for increased rates of skin cancer, particularly of scrotum. Data supporting this association with scrotal cancer and evidence of benzo[a]pyrene levels in oils were provided by Thony et al. (1975)[144]. The association between PAH exposure and occupational cancer risk is the subject of reviews by Lindstedt & Sollenberg (1982)[145] and Boffetta et al. (1997)[146] but the specific risks associated with cutting fluids are not mentioned in either case. The primary cancer sites generally associated with PAH exposure are confirmed as skin, lung and bladder although the specific associations vary according to each PAH and type of exposure.

A later review by Savitz (2003)[147] takes account of many of the individual studies considered in the following section and highlights some of the difficulty with exposure assessment in many of those studies. The evidence for carcinogenicity is summarised with conclusions regarding a wide range of cancers; only rectal and laryngeal cancer were considered to show convincing associations, with evidence of increasing risk with increasing exposure. Others regarded as possible associations but requiring further study were oesophagus, skin and brain.

Much of the following data describes investigation into the relationship between cutting fluid exposure and cancer. A collection of studies relating to the automobile industry are considered together to optimise the interpretation and review.

4.2.1 Automobile workers

An analysis of the mortality of a cohort of automobile workers employed in three US plants was published by Eisen et al. (1992)[148] as a study of MWF exposure but the exposure was not in any way quantified or examined in relation to the specified population. Broad results on the main differences in cancer rates for each plant are given in Table 9. Overall the cancer rates in the cohort did not differ significantly from those expected but there is a difference between the plants, since no cancer type is elevated at more than one plant.

The same cohort formed the basis of a number of additional reports and studies as detailed below:

Hallock et al. (1994)[149] used sampling data on 394 samples, collected from all 3 plants as the basis for exposure quantification. The results showed a significant decline in aerosol concentration between the first sampling period (1958-1969) and the last (1980-1987). In all of the categories of work "Grinding" achieved the highest aerosol levels at all times with by far the greatest exposure occurring in the 1958-1969 time band. The characterisation of MWF exposure is also the subject of a report by Woskie et al. (2003)[150] and draws upon a wide range of published data on MWF composition. The authors conclude that "no one type of MWF or any specific component has been identified as the causal agent in MWF health effects". It is also noted that exposure levels have decreased over the period of time covered by the MWF mortality studies.

Tolbert (1992)[151] used data from two of the plants to investigate associations between types of MWF exposure and cancer rates and found some associations between rectal, laryngeal and prostatic cancer incidence and MWF exposures which formed the basis for more detailed analysis described in later papers in this section. Detailed summary of the analysis is given in Table 9.

A series of case control studies took account of a range of possible confounders (steel, iron, sulphur compounds, chlorinated compounds, biocides, asbestos and acid mists) and showed an excess of laryngeal cancer associated with straight MWF (Eisen et al., 1994)[152] Zeka et al. (2004)[153]; pancreatic cancer and synthetic MWF (Bardin et al.,1997)[154]; oesophageal cancer and soluble and synthetic MWF (Sullivan et al., 1998)[155];brain and prostate cancer and soluble MWF (Thurston et al., 2002)[156]; bladder cancer and straight MWF (Friesen et al., 2009)[157]; rectal cancer and straight MWF (Malloy et al., 2009)[158]. The details of all of these studies are given in Table 9.

Table 9

Data on cancer rates of automobile workers exposed to Metal working fluids (MWF)

Reference, (Location)	Cohort / Study characteristics: Numbers	Confounders Included in analysis and exposure data	No. of deaths/ cases	Exposure categories	Obs/exp or cases/controls	RR, OR, SIR or SMR (95% CI)	Comments
Cohort Studies							
Eisen et al. (1992)[148] (Automobile Industry - 3 US Plants)	Cohort of 46 384 workers who had worked for at least 3 years prior to January 1985 (First employment at 2 plants was in the 1920s and at the 3rd was in 1939)	No quantification of exposure.	10 159 9376 with known cause	Plant I (5491 deaths)			All results given are for white males unless otherwise indicated. # data for black males only
				All cancers	1,085	SMR 1.02 (0.96, 1.08)	
				Leukaemia	65	SMR 1.57 (1.21, 2.00)	
				Pancreatic cancer#	21	SMR 1.70 (1.05, 2.61)	
				Plant II (2625 deaths)			
				All cancers	563	SMR 1.01 (0.97, 1.05)	
				Lung cancer	213	SMR 1.16 (1.01, 1.32)	
				Laryngeal cancer	15	SMR 1.85 (1.03, 3.05)	
				Plant III (736 deaths)	183		
				All cancers	9	SMR 0.98 (0.84, 1.13)	
				Liver cancer		SMR 2.77 (1.26, 5.25)	
Tolbert et al. (1992)[151] (Automobile Industry - 2 US Plants)	Cohort of 33 619 workers working for at least 3 years prior to Dec 1984.				Straight oils SMR	Soluble oils SMR	Synthetic fluids SMR	The data shown are for white males. Analysis of data by exposure duration revealed a stronger association between straight oil exposure ≥ 7.5 years and rectal cancer RR 3.17 (1.62, 6.24) and prostate cancer RR 1.52 (1.01, 2.29).
				Oesophagus	1.18 (0.74,1.79)	1.03 (0.72, 1.43)	0.99 (0.43, 1.94)	
				Stomach	1.12 (0.83, 1.48)	1.19 (0.97, 1.45)	1.28 (0.79, 1.96)	
				Colon	0.79 (0.61, 1.03)	0.85 (0.70, 1.02)	0.83 (0.54, 1.22)	
				Rectum	1.47 (1.04, 2.03)	1.09 (0.81, 1.43)	0.92 (0.42, 1.74)	
				Pancreas	0.80 (0.55, 1.11)	0.77 (0.59, 1.00)	1.03 (0.62, 1.61)	
				Larynx	1.98 (1.26, 2.98)	1.41 (0.95, 2.01)	1.57 (0.68, 3.09)	
				Lung	1.02 (0.90, 1.15)	1.07 (0.97, 1.17)	1.01 (0.83, 1.21)	
				Prostate	1.16 (0.91, 1.46)	1.08 (0.90, 1.28)	1.11 (0.73, 1.63)	
				Brain	1.08 (0.68, 1.64)	1.24 (0.91, 1.66)	0.61 (0.22, 1.33)	
				Leukaemia	1.25 (0.88, 1.71)	1.33 (1.05, 1.67)	1.22 (0.70, 1.98)	
Case-control studies							
Eisen et al. (1994)[152] (Automobile Industry - 3 US Plants)	108 cases of laryngeal cancer. Compared with 538 matched	Cases selected from 10 159 deaths from a cohort of 46 384 automobile workers. Confounders considered are: steel, iron, sulphur		Straight MWF		OR 1.06 (1.02, 1.10)	All OR values are based upon exposure years. Additional analysis showed a significant excess for high level (>0.5 mg/m^3 -years)
				Soluble MWF		OR 0.99 (0.96, 1.02)	
				Grinding		OR 1.01 (0.98, 1.04)	
				Biocide years		OR 1.05 (0.99, 1.12)	
				Steel years		OR 1.02 (0.99,1.05)	
				Iron Years		OR 1.00 (0.97, 1.04)	

Table 9

Data on cancer rates of automobile workers exposed to Metal working fluids (MWF)

Reference, (Location)	Cohort / Study characteristics: Numbers	Confounders Included in analysis and exposure data	No. of deaths/ cases	Exposure categories	Obs/exp or cases/controls	RR, OR, SIR or SMR (95% CI)	Comments
	controls	compounds, chlorinated compounds, biocides, asbestos and acid mists		Aluminium years Sulphur years Chlorine years Asbestos years Acid Mist years		OR 1.00 (0.86, 1.16) OR 1.06 (1.01, 1.12) OR 0.97 (0.79, 1.19) OR 0.98 (0.93, 1.02) OR 0.90 (0.66, 1.22)	Straight MWF exposure (OR 2.23; CI 95%, 1.25, 3.98)
Bardin et al. (1997)[154] (Automobile Industry - 3 US Plants)	97 cases of pancreatic cancer. Compared with 1825 matched controls	Cases selected from 10 159 deaths from a cohort of 46 384 automobile workers Confounders considered are: contaminants of the fluids such as biocides, nitrosamines, steel, iron, aluminium and sulphur		Straight MWF Soluble MWF Synthetic MWF Grinding Grinding synthetic Grinding soluble Machining soluble Biocide years Nitrosamine years Steel years Iron Years Aluminium years Sulphur years		OR 1.01 (0.97, 1.04) OR 1.02 (1.00, 1.05) OR 1.05 (0.97, 1.14) OR 1.02 (1.00, 1.05) OR 1.10 (1.01, 1.20) OR 1.02 (1.00, 1.05) OR 1.03 (1.00, 1.06) OR 1.09 (1.00, 1.02) OR 1.10 (1.01, 1.20) OR 1.02 (0.99, 1.04) OR 1.02 (0.99, 1.05) OR 1.15 (0.96, 1.38) OR 1.02 (0.96, 1.08)	All OR values are shown with a 10-year lag and based upon exposure years Data are also analysed with a 20-year lag but the only OR to increase with that analysis was that for aluminium years OR 1.64 (1.06, 2.54)
Sullivan et al. (1998)[155] (Automobile Industry - 3 US Plants)	53 cases of oesophageal cancer Compared with 971 matched controls	Cases selected from 10 159 deaths from a cohort of 46 384 automobile workers		Straight MWF Soluble MWF Synthetic MWF Grinding Grinding synthetic Grinding soluble Machining soluble Biocide years Nitrosamine years Steel years Iron Years Sulphur years		OR 1.01 (0.97, 1.04) OR 1.1 (0.8, 1.5) OR 3.3 (1.1, 9.6) OR 1.1 (0.9, 1.4) OR 3.3 (1.1, 9.5) OR 1.2 (1.0, 1.5) OR 1.1 (0.9, 1.4) OR 16.0 (1.8, 143.2) OR 3.7 (1.2, 11.1) OR 1.1 (0.8, 1.4) OR 1.1 (0.8, 1.4) OR 1.2 (0.7, 2.1)	All OR values are shown with a 20-year lag and based upon exposure years since this analysis showed the greatest differences between cases and controls
Thurston et al. (2002)[156]	a) 306 prostate cancer deaths were			Prostate Cancer Cumulative soluble MWF exposure: 0 mg/m^3 - years		RR (no lag) RR (30-yr lag)	Analyses presented are based on a non-linear model but are

Table 9

Data on cancer rates of automobile workers exposed to Metal working fluids (MWF)

Reference, (Location)	Cohort / Study characteristics: Numbers	Confounders Included in analysis and exposure data	No. of deaths/ cases	Exposure categories	Obs/exp or cases/controls	RR, OR, SIR or SMR (95% CI)		Comments
(Automobile Industry - 3 US Plants)	compared with more than 6000 controls b) 87 brain cancer deaths compared with 1740 controls			25 mg/m^3 - years		1.05 (0.97, 1.15)	1.05 (0.92, 1.20)	claimed to provide a better fit to the data than conventional approaches.
				50 mg/m^3 - years		1.11 (0.94. 1.31)	1.11 (0.85, 1.45)	
				100 mg/m^3 - years		1.23 (0.88, 1.72)	1.23 (0.72, 2.11)	
				150 mg/m^3 - years		1.37 (0.83, 2.26)	1.54 (0.77, 3.11)	
				250 mg/m^3 - years		2.24 (1.19, 4.19)	6.58 (2.05, 21.16)	
				Brain Cancer				
				Cumulative soluble MWF exposure:			RR (10-20 yr lag)	
				0 mg/m^3 - years				
				0.5 mg/m^3 - years			1.04 (0.98, 1.11)	
				1 mg/m^3 - years			1.09 (0.95, 1.24)	
				5 mg/m^3 - years			1.53 (0.79, 2.96)	
				10 mg/m^3 - years			3.54 (1.40, 8.97	
				15 mg/m^3 - years			15.07 (3.97, 57.17)	
Zeka et al. (2004)[153] (Automobile Industry - 3 US Plants)	laryngeal cancer(78) stomach cancer (77) oesophageal cancer (37)				Soluble (RR)	Straight (RR)	Synthetic (RR)	Data are given for total time. Breakdowns of time of exposure increased the RR in some cases but CI are too wide.
				Larynx	0.97 (0.91, 1.04)	1.07 (1.01, 1.12)	1.03 (0.76, 1.39)	
				Stomach	1.00 (0.95,1.03)	0.96 (0.84,1.08)	0.68 (0.32, 1.43)	
				Oesophagus	0.94 (0.84, 0.04)	0.93 (0.75, 1.15)	0.96 (0.86, 1.07)	
Bardin et al. (2005)[159]	63 cases of hepato-biliary cancer Compared with 569 matched controls	Cases selected from 15 613 deaths from a cohort of 46 400 automobile workers. Result may be confounded by exposure to chlorinated paraffin				Liver cancer OR	Biliary tract cancer OR	Many of the analyses are based on very small numbers thus the confidence intervals are wide.
				Straight MWF				
				0 mg/m^3 - years				
				0-1.0 mg/m^3 - years		0.58 (0.12,1.43)	1.21 (0.42,3.51)	
				>1.0 mg/m^3 - years		0.47 (0.19, 1.16)	2.65 (0.93, 7.54)	
				Soluble MWF				
				<1.4 mg/m^3 - years				
				>1.4-12.6 mg/m^3 - years		0.95 (0.40, 2.29)	0.62 (0.20, 1.91)	
				>12.6 mg/m^3 - years		0.57 (0.21, 1.53)	0.66 (0.14, 3.05)	
				Synthetic MWF				
				0 mg/m^3 - years				
				>0 mg/m^3 - years		1.16 (0.35, 3.81)	0.71 (0.20, 2.56)	
				Chlorinated paraffins				
				0 years				
				> 0 years			3.88 (0.88, 19.96)	

Table 9

Data on cancer rates of automobile workers exposed to Metal working fluids (MWF)

Reference, (Location)	Cohort / Study characteristics			Exposure categories	Obs/exp or cases/controls	RR, OR, SIR or SMR (95% CI)	Comments
	Numbers	Confounders Included in analysis and exposure data	No. of deaths/ cases				
Thompson et al. (2005)[160] (Automobile Industry - 3 US Plants)	99 cases of breast cancer Compared with 626 matched controls	Cases selected from a cohort of 4680 female automobile workers.		Straight MWF Soluble MWF *Model 4* *Model 5* *Model 6* Synthetic MWF		OR 1.05 (0.97, 1.14) OR 1.11 (1.01, 1.22) OR 1.16 (1.01, 1.32) OR 1.18 (1.02, 1.35) OR 0.90 (0.62, 1.30)	The only category of analysis showing differences was for women exposed to MWF during the 10 years preceding diagnosis.
Friesen et al. (2009)[157] (Automobile Industry - 3 US Plants)	153 cases of bladder cancer 480 cases of lung cancer	Cases selected from a cohort of 21 999 automobile workers. Based on a sub-set of the original cohort who were alive and <60 years of age in 1985.		Straight MWF 0 >0 -< 0.15 mg/m^3 - years 0.15 - < 0.52 mg/m^3 - years 0.52 - < 1.86 mg/m^3 - years 1.86 - < 8.98 mg/m^3 - years >8.98 mg/m^3 - years	No. of cases 65 17 18 18 18 17	Hazard ratio 1 1.40 (0.82, 2.38) 1.22 (0.71, 2.09) 1.13 (0.67, 1.90) 1.51 (0.88, 2.61) 2.07 (1.19, 3.62)	An increasing trend in hazard ratio with increasing cumulative exposure to Straight MWF was seen with a lag of 10 and 20 years.
Malloy et al. (2009)[158] (Automobile Industry - 3 US Plants)	90 cases of rectal carcinoma. compared with 1707 non-cases	Cases selected from the cohort of 46 399 automobile workers		Straight MWF 0 >0 - 0.68 mg/m^3 - years 0.68 - 1.93 mg/m^3 - years 1.93 - 10.09 mg/m^3 - years >10.09 mg/m^3 - years		 RR 1.2 (0.6, 2.2) RR 1.6 (0.9, 3.2) RR 1.5 (0.8, 2.8) RR 2.7 (1.4, 5.3)	When the data are analysed using lag periods of 15 and 20 years there is a significant effect at all exposures above 1 mg/m^3 - years.

4.2.2 Workers in other industries

Järvholm & Lavenius (1987)[161] reported an analysis of cancer rates, including both mortality and morbidity in a small Swedish workforce (792) with poorly specified MWF exposure. There was no evidence of an association between exposure and any cancer.

Workers in a bearing manufacturing plant exposed to most of the hazards associated with shipyard metal workers were studied by Park et al. (1988)[162]. Results are shown in Table 10. The small numbers of cases of cancers of interest and the uncertainty over occupation weaken the conclusions of this study. The analysis is subject to all of the normal reservations regarding PMR calculations but particularly for the selection of the control population.

Park (2001)[163] analysed the disease rates in tool grinding operations associated with the automobile industry in the USA, from the perspective of insurance claims. Although rates of pancreas, prostate and lung cancer appeared to be increased at some plants the difference was attributed to diagnostic and claim procedures rather than any real occupational effect.

Russi et al. (1997)[164] studied cases of laryngeal cancer in Connecticut and used two control group comparisons. The analysis failed to demonstrate any association between cutting oil exposure and laryngeal cancer but the study was rather limited both in the selection of cases and controls as well as the exposure assumptions made.

Table 10

Data on cancer rates of workers exposed to Metal working fluids (MWF)

Reference, (Location)	Study / cohort characteristics			Exposure categories	Obs/exp or cases/controls	RR, OR, SIR PMR or SMR (95% CI)	Comments
	Numbers	Confounders Included in analysis and exposure data	No. of deaths				
Järvholm & Lavenius (1987)[165] (Single factory in Gothenberg, Sweden)	792 men who had at least 5 years of exposure to cutting oils between 1958 and 1983			Mortality All cohort All with >20yr since start of exp Morbidity All cohort All with >20yr since start of exp	 42/61.5 33/51.2 67/97.6 56/78.7		Various analyses were made but no significant differences were found
Park et al. (1988)[162] (Bearing manufacturing in Connecticut, USA)	768 hourly employees with 10 or more years' service who died between January 1969 and July 1982	Occupation and exposure data were not very reliable There was a non-significant excess of chronic alcoholism in the grinding group which may have influenced the outcome.	702 death certificates obtained	Digestive organs & peritoneal cancer Stomach cancer Rectal cancer Occupational exposure: Grinding Water-based cutting fluid (comp.) Water-based cutting fluid (restricted)	55/33.65 11/5.53 11/3.58 7/146 8/159 2/53	PMR 1.54 (1.20, 1.99) PMR 1.99 (1.12, 3.54) PMR 3.07 (1.54, 5.50) OR 6.5 (p=0.01) OR 6.9 (p=0.008) OR 5.2 (p=0.13)	
Russi et al. (1997)[164] (Connecticut Tumour Registry)	888 cases of laryngeal cancer in males >50 years old at death. Compared with 752 controls with oral cancer.	Also compared with 3594 general population matched controls		a) Oral cancer controls No exposure Low exposure High exposure b) Population controls No exposure Low exposure High exposure	 	 OR 1.00 (0.7, 1.42) OR 1.48 (1.01, 2.16) OR 0.98 (0.75, 1.27) OR 1.05 (0.81, 1.35)	Data on exposure was derived from recorded occupation at time of death. When the high exposure result compared with oral cancer controls was adjusted for town of residence the Figure became OR 1.42 (0.91, 2.20)

4.2.3 Conclusions on cutting oils and fluids

Information about the use of MWF and the types of MWF (oils, water soluble emulsions and synthetic fluids) used in shipyards is scanty. Cutting oil and fluids are used in cutting and grinding of metals. Steel sheets are cut mainly by thermal cutting in shipyards, but MWFs have probably been used in machining of metals. The main body of data on this subject comes from the automobile industry. Unfortunately the majority of the reports relate to analysis of data from the same cohort so cannot be treated as an independent verification of associations.

The long-established risk of skin cancer associated with poorly refined mineral oils is the primary link, but such oils were eliminated from use at different times in different work-places so relevance of this risk to shipyard employment cannot be established from the available data. However, many different cancers have been shown to be significantly in excess in the automobile industry cohort (Pancreas, Leukaemia, Lung, Liver, Larynx, Oesophagus, Prostate, and Bladder). There appears to be little reproducibility in the cohort data, even between different plants in the same study. The cancer associations present in the data would need some independent verification from other cohorts, for firm conclusions to be drawn. The excess cancers seen in some studies may have some occupational association but it cannot be certain that they are related to metal-working. Grinding seems more frequently to be the occupation associated with risks and has been identified in one study as the procedure which is likely to result in the largest exposure to MWF mists.

A number of analyses of case-control studies of bladder cancer (Gonzalez et al., 1989[166]; Steineck et al., 1990[167]; Yamaguchi et al., 1991[168]; Notani et al., 1993[169]; Siemiatycki et al., 1987[170]; Teschke et al., 1997[171]) either support the association of bladder cancer with cutting oil/fluid exposure or show no relevant associations. Specific causative agents are not identified in any of these studies.

The association with laryngeal and prostate cancer seen in the original cohort study were each confirmed by case-control studies, but have not been confirmed in other independent studies. While this may be a real association in this cohort it is uncertain whether it is a generally applicable link or whether it is specific to the MWF identified by the case-control study. The association of cutting oils with skin cancer has been demonstrated historically, related to PAH exposure but did not feature in the studies reviewed here.

4.3 Painting

Painting in shipyards is considered to be sufficiently similar to work in other industries for data on occupational risk from those sources to be reviewed. It is likely that shipyard painters will have additional exposures not experienced in other industrial sectors such as anti-fouling (e.g. organo-mercury compounds, copper oxide, arsenic, organo-tin compounds) and anti-rust paint (e.g. chromates, lead oxide, zinc compounds, coal tar pitch in black paints). Painters may also have worked in areas where asbestos was used.

4.3.1 General reviews

A review of painting[19] as an occupation was completed by IARC in 1989 and provides the starting point for this review. It was concluded that there was sufficient evidence for the carcinogenicity (bladder and lung) of occupational exposure as a painter. This conclusion was based upon a wide range of evidence but particularly on epidemiological data in which a range of occupationally-related cancers were described but lung cancer rates were consistently increased. The main sources of data considered were cohort studies which are summarised in Table 11 below.

A large number of case-control studies provided supporting evidence of an association related to lung cancer. Other case-control studies indicated a possible excess risk of cancer of the bladder, oesophagus, stomach, bile duct, pancreas, leukaemia and prostate.

Bosetti et al. (2005)[172] reviewed the available studies related to bladder cancer risk in painters, covering the period from the IARC review until 2004. Four cohort studies were reviewed along with 19 case-control studies and a pooled analysis of 11 case-control studies. The results of all studies were incorporated into a meta-analysis applying weightings to each study proportional to the precision. The pooled RR from the cohort studies was 1.10 (CI 95%; 1.03, 1.18) based on a total of 893 cases. The lack of data on exposure makes it impossible to consider potential causative agents. The potential interactions between painting and smoking were also beyond the scope of the available data. The pooled analysis of case-control studies gave a RR of 1.35 (CI 95%; 1.19, 1.53). The difference between the case-control and cohort study analyses suggests some informational bias in the former studies. Most studies did not have sufficient data on duration and time-related factors to allow any assessment of causality between recent exposure to painting and bladder cancer risk.

Table 11

Cohort studies considered in IARC review of Painting

Citation	Site of cancer	Comments
Chiazze et al (1980)[173]	Lung	Non-significant RR of 1.4 among 226 deaths among spray-painters from 4215 total deaths. in 5 large US automobile plants
Englund (1980)[174]; Engholm & Englund (1980)	Oesophagus, liver & bile ducts, lung, larynx, and lymphatic leukaemia	Based on 2740 deaths from a cohort of 30 580 members of the Swedish painters' Union. Excesses were seen for all the cancer sites listed but oesophagus (17 cases - SIR 2.15; 1.24, 3.40) liver (12 cases - SIR 2.00; 1.03, 3.49) and lung (81 cases - SIR 1.28; 1.06, 1.52) were significant
Dalager et al. (1980)	Lung	A study of spray painters in the aircraft industry. 50 cancers in total and 21 lung cancer cases but both total and lung cancer rates were significantly higher than background
Mikkelson (1980)		2609 painters in Copenhagen area. No increased risk of cancer when compared with bricklayers from the same area.
Whorton et al. (1983)	Bronchus, Lung, Trachea, Pleura	6424 union members in San Francisco area from 6 occupations. Increased risk among painters at listed sites.
Matanoski (1986)[175]	Stomach, Lung,	5313 deaths (1281 cancers) from a group of 57 175 Painters who were construction union members from USA. Lung (326 cases - PMR 1.18; 1.06, 1.32) Stomach (50 cases - PMR 1.36; 1.0, 1.80) Non-significant excess also noted for bladder cancer and leukaemia.
Stockwell & Matanoski (1985)[176]	Lung	Case-control study of 1214 lung cancer cases in New Yok. Painting was associated with a high risk (RR 2.8; 1.5, 5.2). May have been confounded by use of asbestos based fillers.
Olsen & Jensen (1987)	Lung	Classification of longest employment for all 93,810 cases of cancer on Danish Registry revealed a SPIR for lung cancer in painters of 1.49 (1.19, 1.85) based on 79 cases.

Agents which have historically been present in the working environment of painters, and which may contribute to cancer risk, have been identified in many reviews. These include substances such as asbestos, aromatic amines, chromates, organic solvents, cadmium[177].

Baker (1994)[178] reviewed the health effects of solvents and in a brief summary of available data noted increased cancer rates reported in several studies associated particularly with the lymphatic and haematopoietic system. Other cancers reported to be increased in solvent exposed workers were oesophageal, liver and cervical. The available data on white spirit was reviewed by IPCS in 1996[179]and increased relative risks were identified for cancer of lung, kidney, prostate and Hodgkin's lymphoma, however the nature of the studies and lack of detailed exposure information do not allow separation of these effects from other exposures of the studied population.

Dalager et al. (1980)[180] reported mortality data from a cohort of aircraft maintenance workers, including 977 spray-painters exposed to zinc chromate paints. The cohort was based upon every employee of two large US aircraft maintenance bases in the 10 years preceding 1959. The report is based upon deaths which occurred in this cohort up to the end of 1977. The frequency of specific causes of death was compared with the general US population. There were 202 deaths among the painters, which showed a significant excess of cancer (PMR 1.36),

particularly of the respiratory tract (PMR 1.84). The PMRs increased with duration of employment. Since median age at first employment was 43 years the lack of data on previous occupation is a serious deficiency of this analysis. Additionally information on smoking habit and alcohol consumption was not available. While the excess of lung cancer is consistent with other studies on painters, this study does not provide sufficient evidence to conclude on the role of chromate as a potential causative agent.

4.3.2 Cohort studies

Only one study is available referring to risks for painters in shipyards (Chen et al., 1999)[44] and this study identified no specific risk for that occupation (for details see Table 12). Cancer rates were similar in the painters and the background male population of Scotland. All other data is based upon painters in other industries so may have exposure patterns which are not completely relevant to shipyards.

Aronson et al. (1999)[181] investigated mortality in a large cohort of Canadian employees. The only significant occupational association for painters was for Brain cancer but the reliability of this analysis must be questioned due to the small number of cases and the very limited approach to determining the occupation of each individual.

A study of painters from Geneva is described by Gubéran et al. (1989)[182]. Analysis was conducted on mortality rates and on cases arising in a cohort. Significantly increased mortality rates were found from both lung cancer and from gall bladder cancer among the cases of cancer reported in the cohort the same cancer featured in addition to an excess of bladder and testis cancer. Details of the cancer rates are given in Table 12. An excess of lung cancer was suggested to be related to asbestos or chromate exposure but without any direct evidence.

A study of cancer rates in Nordic painters (Skov et al., 1993)[183] identified excess cancers of mouth, pharynx and lung in at least one of the four countries investigated. The study was based upon census reports and cancer registry deaths. The analysis makes no attempt to discriminate those with longer exposures.

Terstegge et al. (1995)[184] compared cause of all deaths in painters from the Netherlands with expected rates in the general population. Although overall cancer rates were higher in the painters (3266 compared with 3050 expected) the only cancer which was significantly in excess was lung cancer (Table 12).

Steenland & Palu (1999)[185] reported a follow-up of a cohort of US painters originally reported by Matanoski et al. (1986)[175]. The results are summarised in Table 12 and indicate an excess of lung and bladder cancer in painters. The absence of adjustment for confounders could be sufficient explanation for the differences seen, although the differences are still present when the analysis is conducted using non-painter members of the cohort for comparison. The authors describe a decline in risk compared with those exposed before 1930 and with long-term employment, perhaps implicating some factor which is no longer a significant part of painter exposure.

4.3.3 Cross-sectional studies

Bethwaite (1990)[186] reported increased rates of multiple myeloma and bladder cancer in painters ≤ 60 years of age, after analysing all registrations on the New Zealand cancer registry over a 4-year period (See Table 12 for details).

4.3.4 Case-control studies

Stockwell & Matanoski (1985)[176] examined the lung cancer cases (65 vs 182 controls) from a large cohort study[175] of US painters. Lung cancer was associated with painting, use of spackling, and with not wearing a mask/respirator (see Table 12).

Lindquist et al. (1987)[187] studied 125 Swedish Leukaemia patients and obtained detailed personal histories by interview from these patients and from 125 controls. Details of the risks are given in Table 12. The results support an association of painting as an occupation with leukaemia and identify solvent exposure as a potential cause.

Jensen et al. (1987)[188] reported a case-referent study on bladder cancer which was also considered in the review of painting-related cancer by IARC (1989)[19]. Bladder cancer in painters was also the subject of a case-control study reported by Myslak et al. (1991)[189].

4.3.5 Meta-analysis

The relationship between occupation as a painter and lung cancer was explored by Guha et al. (2010)[190] using data from a total of 47 independent studies (18 cohort / record-linkage studies and 29 case-control studies). The studies in the analysis included >11 000 cases/deaths from lung cancer among painters. Overall the conclusions of IARC (1989)[19] were reconfirmed. A similar exercise has also been performed for bladder cancer (Guha et al., 2010)[191] in a total of 41 independent studies (2 cohort, 9 record-linkage and 30 case-control) with >2900 cases or deaths from bladder cancer among painters. Again, the findings supported the previous IARC conclusions that occupational exposure in painters is causally associated with bladder cancer. The analysis showed both elevated overall risk and an increased risk with increased exposure.

A further meta-analysis of both lung and bladder cancer in painters, has been prepared by Bachand et al. (2010)[192] and is based on a careful selection of the studies and with numerous alternative analyses (Table 12). While the basic analysis confirms a weak association between the rates of bladder and lung cancer in painters the application of various adjustments demonstrates that in this analysis the association may be explained by factors other than those resulting from occupation. However the excess risk identified is consistent with the results of Guha[190,191].

Table 12

Data on cancer rates among Painters

Reference, (Location)	Cohort / Study characteristics			Categories		Observed/expected	RR, OR, SIR PMR or SMR (95% CI)	Comments
	Numbers	Confounders Included in analysis and exposure data	No. of deaths/cases					
Cohort Studies								
Aronson et al. (1999)[181] (Canada)	457 224 male and 242 196 female Canadians employed between 1965 and 1971 Mortality data for 1965-1991	Very poor identification of occupation; (based upon a information from a single year (1971)		Brain Cancer in Painters			RR 3.79 (1.70, 8.48)	
Gubéran et al. (1989)[182] (Painters resident in Geneva)	Cohort of 1916 painters at time of 1970 census. Followed from 1971 to 1984	No individual data on life-style attributes of the cohort but suspected higher level of alcohol consumption than general population. Analysis distinguished between cases of cancer and deaths from cancer		Deaths				Only those cancers showing a significant difference are given.
					All sites	96/75.4	SMR 1.27 (1.07, 1.51)	
					Gall bladder	3/0.7	SMR 4.29 (1.17, 11.08)	
					Lung	40/23	SMR 1.74 (1.31, 2.26)	
				Cases				
					All sites	159/132	SIR 1.20 (1.05, 1.37)	
					Gall bladder	3/0.8	SIR 3.75 (1.02, 9.69)	
					Lung	40/27.3	SIR 1.47 (1.11, 1.91)	
					Testis	5/1.6	SIR 3.13 (1.23, 6.57)	
					Bladder	13/7.6	SIR 1.71 (1.01, 2.72)	
Skov et al. (1993)[183] (Denmark, Norway, Sweden, Finland)	Total of 87 004 painters from census records from 1960 (Norway and Sweden) or 1970 (Finland and Denmark).	Follow-up of: 14yr (Norway) 19yr (Sweden) 10yr (Finland and Denmark) There was an elevated risk for cirrhosis of the liver in Finland but no data available on smoking habits or alcohol intake			Mouth cancer	Sweden (29/18.45) *All others NS*	RR 1.57 (1.05, 2.26)	Risks for Oesophagus, Liver, Larynx and Bladder were not increased in any Nordic country. (1.86; 1.25, 2.68).
					Pharynx	Norway (21/9.96) Denmark (10/4.40) *All others NS*	RR 2.11 (1.31, 3.22) RR 2.27 (1.09, 4.18)	
					Lung	*Norway (251/190.50)* *Sweden (493/389.02)* *Finland (118/94.35)* *Denmark (181/130.19)*	RR 1.32 (1.17, 1.49) RR 1.27 (1.16, 1.39) RR 1.25 (1.04, 1.50) RR 1.39 (1.20, 1.61)	
Terstegge et al. (1995)[184] (Netherlands Painters)	9812 painters who died 1980-1992	No exposure data or individual life-style data are available in this study		Lung		1,480/1,236.7	PMR 119.7 (113.7, 125.9)	No other cancer was significantly increased in this study.
Steenland & Palu (1999)[185] (Members of the US Painters	Follow-up of a previous study[175] included in IARC review.	Alcohol asbestos and smoking differences were not considered.				SMR All	SMR (20yrs lag)	SMR is in respect to general population whereas the RR is based on the
				Lung		1.23 (1.17, 1.29)	1.24 (1.18, 1.31)	
				Liver		1.25 (1.03, 1.50)	1.17 (0.95, 1.44)	
				Bladder		1.23 (1.05, 1.43)	1.25 (1.06, 1.47)	

Table 12

Data on cancer rates among Painters

Reference, (Location)	Cohort / Study characteristics: Numbers	Confounders Included in analysis and exposure data	No. of deaths/cases	Categories	Observed/expected	RR, OR, SIR PMR or SMR (95% CI)	Comments
Union)	Members of US Painters' union born before 1940 and alive in 1975. Followed up to 1994.				RR All	RR (20yrs lag)	comparison of painters and non-painters from the union membership.
				Lung	1.23 (1.11, 1.35)	1.32 (1.16, 1.51)	
				Liver	1.36 (0.87, 2.11)	1.16 (0.69, 1.93)	
				Bladder	1.77 (1.13, 2.77)	1.55 (0.96, 2.51)	
Chen et al. (1999)[44] (UK dockyard)	1292 male painters working in a dockyard in Scotland for ≥ 1 year between 1950 and 1992.		205	All sites	58/53	PMR 1.10 (.84, 1.43)	No increased risk of any cancer
Cross sectional studies							
Bethwaite et al. (1990)[186] (New Zealand Cancer Registry)	19 904 Males aged ≥ 20 entered on the NZ cancer registry 1980-1984.	There is little data available on occupation/exposure and potential confounders. A crude assessment of the lack of impact of smoking is made on the basis of incidence rates of other smoking-related cancers, but there is some evidence that smoking is more prevalent in painters than in the general population		Urinary	38	OR 1.53 (1.10, 2.14)	Occupation was current or most recent occupation at time of registration. for each cancer site the registrants for other sites formed the control group
				Bladder	24	OR 1.52 (1.00, 2.31)	
				Age 20-59	9	OR 2.27 (1.15, 4.48)	
				Age ≥ 60	15	OR 1.27 (0.75, 2.15)	
				Kidney	14	OR 1.45 (0.85, 2.50)	
				Age 20-59	7	OR 1.94 (0.91, 4.19)	
				Age ≥ 60	7	OR 1.16 (0.54, 2.48)	
				Multiple Myeloma	10	OR 1.95 (1.05, 3.65)	
				Age 20-59	5	OR 4.23 (1.80, 9.91)	
				Age ≥ 60	5	OR 1.27 (0.52, 3.10)	
Case-control studies							
Stockwell & Matanoski (1985)[176] (Lung cancer in US Painters)	69 lung cancer patients and 182 controls (Only 69 cases were included in the analysis out of 124 identified).	Smoking was adjusted for. Questionnaires were completed by next-of kin for 94% of cases but only 33% of controls.		Painter			An interaction was found between not wearing a mask and lung cancer (OR 5.54 (1.01, 29.33)
				Usual occupation	51/98	OR 2.75 (1.45, 5.21)	
				Recorded trade	37/66	OR 3.17 (1.43, 7.05)	
				Ever worked	52/103	OR 2.57 (1.34, 4.94)	
				Ever used spackling (asbestos)	53/112	OR 5.23 (1.89, 14.48)	
				Never used mask/respirator	37/86	OR 1.57 (0.86, 2.87)	

Table 12

Data on cancer rates among Painters

Reference, (Location)	Cohort / Study characteristics			Categories	Observed/expected	RR, OR, SIR PMR or SMR (95% CI)	Comments
	Numbers	Confounders Included in analysis and exposure data	No. of deaths/cases				
Jensen et al. (1987)[188] (Copenhagen residents)	371 cases between 1979 and 1981 compared with 771 local controls	Detailed histories were obtained by interview. Adjusted for age, sex and smoking in analysis		Painters -all Painters for > 20 years	13 8	RR 2.54 (1.12, 5.73) RR 4.1 (1.2, 13.9)	
Lindquist et al.(1987)[187] (Leukaemia Patients)	125 Swedish leukaemia patients compared with 125 controls.	Patients interviewed directly. Median duration of exposure of painters was 16 years. Consideration was given to smoking, X-ray exposure, anaesthesia and non-professional painting.		Painter Solvent exposed non-painter	13/1 26/7	OR 13 (2.0, 554) OR 3.7 (1.6, 10.1)	Daily solvent use was reported by all the painters.
Myslak et al. (1995)[189] (German Painters, Dortmund)	403 bladder cancer patients treated 1984-1987 Compared with a reference group of 426 prostate cancer patients.	No difference between smokers and non-smokers		Painters 3 different referent populations: Area 1 Area2 Area 3	21/8	RR 2.76 ** RR 2.7 (1.8, 4.1) *** RR 2.8 (1.9, 4.2) *** RR 3.5 (2.4, 5.2) *** ** p < 0.01 ***p < 0.001	The painters generally had very long duration of exposure (mean 29 years) from an early age (mean 14 years) and approximately 45 years from first exposure to diagnosis.
Meta-analysis							
Guha et al. (2010)[190] (Lung)	47 studies (18 cohort or record-linkage studies and 29 case-control studies)			All painters Non-smokers Painters ≥ 20 years Painters < 20 years		RR 1.35 (1.29, 1.41) RR 2.00 (1.09, 3.67) RR 2.00 (0.77, 1.65) RR 1.37, (0.89, 2.13)	
Guha et al. (2010)[191] (Bladder)	41 studies (2 cohort, 9 record-linkage and 30 case-control)			All painters Adjusted for all occupational exposures including smoking Painters ≥ 10 years Painters < 10 years		RR 1.25 (1.16, 1.34) RR 1.27 (0.99, 1.63) RR 1.81 (1.20, 2.75) RR 1.41 (1.00, 2.01)	

Table 12

Data on cancer rates among Painters

Reference, (Location)	Cohort / Study characteristics			Categories	Observed/expected	RR, OR, SIR PMR or SMR (95% CI)	Comments
	Numbers	Confounders Included in analysis and exposure data	No. of deaths/cases				
Bachand et al. (2010) [192]	24 case-control and 7 cohort studies for lung cancer 40 case-control and 4 cohort studies for bladder cancer	Applying external adjustments did consistently but not entirely reduce the risk; estimates indicating some confounding due to smoking. Adjusting for SES (socioeconomic status) made the greatest difference to results.		All case-control studies - lung SES adjusted case-control - lung All cohort studies - lung mortality Smoking adjusted cohort - lung mortality All case-control studies - bladder SES adjusted case-control - bladder All cohort studies - bladder mortality Smoking adjusted cohort - bladder mortality		OR 1.18 (1.09, 1.28) OR 1.09 (0.98, 1.22) RE 1.38 (1.34,1.41) RE 1.19 (0.98, 1.44) OR 1.28 (1.17, 1.41) OR 1.17 (0.94, 1.46) RE 1.14, (1.06, 1.22) RE 1.22 (1.06, 1.40)	

4.3.6 Conclusions on Painting

Painters in shipyards are exposed not only to substances associated with their trade but also to the general background of asbestos and welding fume and this will be considered later.

A review of occupational bladder cancer by Clayson (1976)[193] identifies 4-aminobiphenyl, 2-naphthylamine, benzidine, 1-naphthylamine and 4-nitrobiphenyl as the main chemical substances responsible for occupational bladder cancer in man. Although painters, apart from Japanese kimono painters, are not specifically mentioned in this review the known use of aromatic amines in some paints cannot be ignored. A second review by the same author in 1981[194] mentions only three of the chemical agents (4-aminobiphenyl, 2-naphthylamine and benzidine) since effects of 1-naphthylamine were considered due to contamination with the 2-isomer. Since aromatic amines are deactivated by metabolism via N-acetyltransferase a low level of this enzyme activity would render subjects more vulnerable to the carcinogenic action of these dyes. Golka et al. (1997)[195] and (2001)[196] showed that slow acetylators are over-represented in painters suffering from bladder cancer thus reinforcing the causative connection between benzidine exposure and bladder cancer.

Yasunaga et al. (1997)[197] studied the mutations in the p53 gene in 26 patients with bladder cancer and known exposure to aromatic amines and concluded that the pattern of gene changes was different for occupational and non-occupational lesions. The data are rather varied and no specific account is made in the analysis for the association between smoking and bladder cancer. More reproducible evidence would be required before any conclusions could realistically be drawn about the relationship between the nature of lesions and their causation.

Although a wide range of associations of cancer with the occupation of painting emerge from the studies reported the only associations which show any level of consistency are with lung and bladder cancer. IARC already acknowledged these associations in 1989 when concluding that painting as an occupation was linked to human cancer. This conclusion was supplemented by IARC in 2010[198] by confirmation of an association of pleural mesothelioma with the occupation of painting in addition to confirming links with bladder and lung cancer.

The IARC conclusions are reinforced by a range of studies including meta-analysis. However, there may be some confounding of the magnitude of the risk estimate by smoking and other factors, as both cancer types are also associated with smoking. Causative agents have not been specifically identified for any of the cancer types associated with this occupation but solvents, asbestos fillers, aromatic amines and chromate pigments are speculated to be the most likely candidates.

Benzene is established by IARC[199] as a human carcinogen, mainly associated with leukaemia and other cancers of the Haematopoietic/Lymphoreticular system. Exposure of painters to solvents containing benzene as an impurity is likely to bring some risk of these cancers but no study has so far identified these as associated with painting as an occupation, thus they are not considered further.

4.4 Plumbers & Pipefitters

Plumbing and Pipefitting is one of the occupations most commonly associated with exposure to asbestos, due to use of lagging and insulating materials thus many of the issues raised in the review of asbestos carcinogenicity (section 3.3) apply to this occupation.

No studies were identified which specifically investigated this occupation in shipyards but the following studies serve to illustrate the available data.

Kaminski et al. (1980)[200] reported a mortality analysis of plumbers and pipefitters carried out by NIOSH and based upon 3794 death benefit claims made from the United Association of Journeymen and Apprentices of the Plumbing and Pipefitting Industry during 1971. The year was selected at random from records extending between 1968 and 1975. Analysis was restricted to 3369 white US males for whom death certificates could be obtained. Analysis was made on the basis of 5 trade categories (plumbers, pipefitters/steamfitters, sprinkler-fitters, metal tradesmen, lead burners). For the entire study group PMRs were calculated in comparison with the 1971 US white male population and significant excess of malignant cancer was found with specific excess of cancer of oesophagus and respiratory system (particularly lung, bronchus and trachea). Seven cases of mesothelioma were reported although the death certificate in several cases was not specific about the location. Most cases of mesothelioma and asbestos-related disease occurred in the trade group "Steamfitters". The majority of the excess of other cancers were associated with the trade "Plumber" with significant excess of malignant cancer, digestive organs and peritoneum, oesophagus, respiratory system, lymphatic and haematopoietic tissues. The weakness of the data-set and the analysis (particularly the tendency of the analysis to overestimate risks) is acknowledged by the authors.

Gallagher & Threlfall (1983)[100] reported a study of mortality in metal workers reviewed earlier, and which included "Plumber" as an occupational category. Lung cancer (PMR 1.44; 95% CI 1.21, 1.71) and Pleural cavity cancer (PMR 14.41; 95% CI 5.28, 31.37) were associated with the occupational category and are a typical picture of cancer rates following asbestos exposure.

Cantor et al. (1986)[201] reported a study of 7121 deaths between 1960 and 1979 of members of the Californian United Association of Plumbers and Pipefitters. Death certificates were analysed or all deaths logged on the Union records and PMR was calculated compared with the standard US population. In the total group there was an increased PMR for stomach cancer 1.29 (CI 95% 1.06, 1.58), respiratory system cancer 1.40 (CI 95% 1.30, 1.51) brain cancer 1.50 (CI 95% 1.16, 1.94) and lymphopoietic cancer 1.24 (CI 95% 1.06, 1.44). When trades were analysed separately plumbers also had an excess of kidney and brain cancers not present in other categories. The analysis does not identify pleural cancer as a separate category but in the discussion of the results the authors specify that 16 deaths were attributable to mesothelioma 12 of which were pleural; this gave a RR of 3.9 for this cancer in this group.

The type of analysis used in the above studies is generally recognised as likely to overestimate risks thus, without further substantiation, the results are not considered sufficient basis for an occupational association regarding stomach, kidney, brain and lymphatic cancer. The

primary risk for plumbers and pipefitters is considered to be lung and pleural cancer related to asbestos exposure. Due to the direct use of asbestos this group would be considered a high risk group for asbestos-related cancer.

4.5 Wood-worker

Employment as a wood-worker or carpenter/joiner in shipyards may be a rather mixed situation compared with other sectors since hardwood features in many marine fittings thus providing exposures to dust which are more like those of the furniture industry than of general carpentry. The additional exposure to asbestos and welding fume, common to all shipyard workers will add to the overall cancer risk for this group.

Acheson et al (1981)[202] reviewed the incidence of nasal cancer in the UK and association with occupation and showed, amongst others, an excess in woodworkers. The SIR values calculated for different sub-groups of woodworkers are indicated that the excess risk for cabinet and chair-makers, machinists and other woodworkers was significant while that for carpenters and joiners was not.

The risks associated with carpentry and joinery were reviewed by IARC in 1981[203] with the conclusion that the epidemiological evidence was not sufficient to make a definitive assessment of carcinogenic risk. The possibility of association with Hodgkin's disease and with nasal adenocarcinoma is mentioned, although the latter is only recorded in some studies and may be confounded by prior employment in other occupations, such as furniture-making. Evidence for increased risk of lung, bladder and stomach cancer is said to be inadequate.

Hernberg et al. (1983)[204] reported a case-referent study of nasal and sino-nasal cancer with 167 cases drawn from the cancer registries of Denmark, Finland and Sweden. Exposure to mixed hardwood and softwood dusts was associated with an increased risk of cancer (OR 12.0; CI 95%; 2.4, 59.2). Detailed analysis of the exposure suggests that hardwood exposure is primarily responsible and is associated with adenocarcinoma. Comparison of rates in smokers and non-smokers showed a slightly greater risk from mixed hardwood and softwood dust exposure among smokers. Softwood dust exposure did not result in a significant additional risk of nasal cancer and adenocarcinoma did not feature in that exposure group.

A review of the data by IARC in 1987[205] classified the evidence as limited, repeating that it was possible that some cases of nasal adenocarcinoma had derived from exposures during previous employment in the furniture industry. The same two cancer types (Hodgkin's lymphoma and nasal adenocarcinoma) are confirmed as the most likely associations.

In 1995 a review by IARC[206] concluded that there is sufficient evidence in humans for the carcinogenicity of wood dust and did not make a distinction between hard-wood and soft-wood dusts, although most of the evidence for nasal adenocarcinoma seemed to be related to hard wood.

Teschke et al. (1997)[171] reported a study of 48 cases of nasal cancer registered with the British Columbia Cancer Agency between 1990 and 1992. For those ever employed in the textile

industry there was an excess of nasal cancer (OR 7.6; CI 95%; 1.4, 56.6); no other occupation showed a significant association including carpenters/wood-workers and shipbuilding workers.

The position that the source of wood dust is not important was upheld by a retrospective study of exposure for 28 cases of nasal adenocarcinoma in Germany (Jansing et al. (2003)[207]. One study of shipyard workers identified an excess of oral/nasopharyngeal cancer (SMR 6.20; CI 95%; 2.27, 13.5) in woodworkers (Krstev, 2007)[22]. Although no other data were identified which were specifically relevant to assessing the cancer risk of shipyard wood-workers/carpenters on the basis of the study above and of the IARC review it must be considered that this group may have a specific additional cancer risk, particularly of nasal adenocarcinoma, and this is considered in the later sections.

4.6 Electrician

Electricians may be exposed to EMF and exposures from other tasks near-by. There is only very limited evidence to suggest an association between EMF exposure and brain cancer or leukaemia as considered under section 4.6. Only two studies report cancer rates for electricians. The SMR for mesothelioma was significantly elevated in a shipyard in the USA (Krstev et al., 2007)[22], but the lung cancer risk of this occupation was not increased in a Norwegian shipyard (Danielsen et al., 2000)[43]. On the basis of this evidence and available exposure data (Williams et al., 2007) [3] it is considered that shipyard electricians may have an increased risk for asbestos-related cancers but no additional job-specific risks.

4.7 Other Shipyard Occupations and exposures

Shipyard occupations have been listed in detail in very few publications. This review has attempted to obtain data on any cancer risk associated with the following occupations, in addition to those so far described:

engine fitter
oiler
greaser
maintenance mechanics
burner
crane operator
rigger
labourer

Specific occupationally-related cancer risks have not been identified for these categories, thus they will be discussed only under the general classification of shipyard workers.

5. CAUSAL LINKS BETWEEN SPECIFIC CANCERS AND SHIPYARD OCCUPATIONS

The current review was initiated to obtain an understanding of the cancer risk associated with working in shipyards, as a potential assistance to those responsible for determining entitlement to claims for occupationally-related disease.
The review has specified the main hazards known to be present in shipyards and considered potential exposure to those hazards, including consideration of occupations which have been classified as associated with carcinogenic exposures, without further identification of causative agents. A summary of these hazards is given in Table 13 below.

Table 13

Shipyard hazards, cancer types and IARC classification

Hazard	Cancer type	IARC class	Comments
Asbestos	Lung, Mesothelioma, Larynx	1	
Benzene	Leukaemia	1	
Cadmium	Lung	1	
Chromium (VI)	Lung	1	
Coal tar pitch	Skin, lung	1	
Extremely low electromagnetic field (EMF)	Leukaemia, brain	2B	
Ionizing radiation	Leukaemia,	1	
Lead	Stomach	2B	
Metal-working fluids	Skin	1	Poorly refined oils
Nickel	Nasal cavity, lung	1	
Painting	Bladder, lung	1	
Quartz	Lung	1	
Solvents Dichloromethane Perchloroethylene Trichloroethylene		 2A 2A 2B	
Ultraviolet radiation (UVR)	Skin, ocular melanoma	1	
Welding and thermal cutting fumes (total particulates)	Lung	2B	
Wood dust	Sino-nasal and naso-pharyngeal cancer	1	

Note - IARC classifications are: 1 carcinogenic to humans; 2A Probably carcinogenic to humans; 2B Possibly carcinogenic to humans; 3 not classifiable as to carcinogenicity in humans; 4 probably not carcinogenic to humans

For some cancers there is evidence from the reviewed data for increased risk among shipyard workers. The following sections explore the possible causes of those increased risks.

5.1 Asbestos and cancer among all shipyard workers

Asbestos, as a known human carcinogen, can cause lung and larynx cancer as well as mesothelioma. Considering only lung cancer and mesothelioma the risks of the two cancer types have different time-profiles and lung cancer incidence is particularly increased amongst those who are also smokers, while mesothelioma rates are independent of other factors. The precise relationship between the two factors for lung cancer is debated but a recent paper concludes that smoking and asbestos exposure are at least additive in a linear model. Although there is some difference between different types of asbestos in the cancer rates, and this has been debated in the literature at length, this is not considered further since most of the known exposure in shipyards was either not specified or was to the putatively more hazardous varieties.

The background exposure to asbestos experienced by almost all shipyard workers over many years cannot be quantitatively determined for any individual or group. The limited data available and reviewed in Section 3.3 suggest that exposure levels were likely to be high in all shipyards until the mid 1970s. For individual cases it is however possible to gain some impression of the level of risk carried by an individual from some of the non-cancer asbestos pathology (e.g. pleural plaques)[60;208] since the incidence of this pathology also appears to be correlated with exposure. It is considered plausible that asbestos exposure for many shipyard workers has been sufficient to carry a significant extra risk for cancer.

Since mesothelioma incidence is so low in the general population a raised incidence is often an indicator of asbestos exposure. The presence of a significant incidence of mesothelioma cases in many shipyard studies supports the conclusion that asbestos exposure levels were sufficient to cause these cancers and could also be the cause of excess lung cancer risk.

Lung cancer is the commonest of human cancers in many countries and strongly associated with smoking of tobacco. Lung cancer is also the most consistently demonstrated cancer to be in excess in general shipyard populations, compared with the normal background. The most obvious factor to consider when examining occupational lung cancer rates is the smoking habit of the work group, compared with a working population not exposed to occupational carcinogens. For a considerable number of the studies reviewed these data are either absent or incomplete, thus the contribution of smoking to the excess cancers cannot be fully established. However in some of those studies that adjust for smoking differences this excess risk is still present, thus is evidently due to some other factor. Although some sub-groups of workers do have specific exposures which can be directly linked to a risk of lung cancer these do not constitute a sufficient proportion of the workforce to be the source of the overall excess.

The commonest occupational contributor to excess lung cancer is asbestos exposure IARC[48;49] and in shipyards this was not routinely monitored before the 1970s, when exposure was potentially at its highest (See Section 3.3). It is considered highly probable that asbestos exposure is the major cause of excess lung cancer in shipyard workers. Although laryngeal cancer has been agreed by IARC to be an additional site for cancer caused by asbestos (Straif, 2009)[50] laryngeal cancer has been identified in only one study of shipyard workers[45] but this supports the conclusion that laryngeal cancer must also be considered as an occupational risk for shipyard workers.

5.1.1 Quantification of asbestos cancer risk

Since it is not established generally which type of asbestos shipyard workers have been exposed to this limits the possibility for quantification of risk as that for each type of asbestos is not identical with orders of magnitude difference in the risk levels for mesothelioma between the different types. For example Hodgson and Darnton (2000)[53] reviewed a wide range of data on cohorts of workers with some record of cumulative asbestos exposure. Broadly the pattern of results from a range of studies was consistent and showed significantly different mesothelioma risk levels for chrysotile, amosite and crocidolite asbestos in the ratio 1: 100: 500 but with similar rates for lung cancer with the two amphiboles and a ratio between these and chrysotile of between 1: 10 and 1: 50.

The same authors (Hodgson & Darnton, 2010)[209] commented on a detailed analysis of lung and mesothelioma rates by Loomis et al. (2009)[210] who studied textile workers exposed primarily to Chrysotile asbestos. Hodgson & Darnton observed that the Loomis study confirmed the background relative risk of excess lung cancer as 0.1% /fibre/cm^3.yr. For mesothelioma it was noted that the difference between the different asbestos types may not be as large as originally thought.

5.2 Ionizing radiation and leukaemia

At exposures significantly higher than are recorded for shipyards the causality of leukaemia by ionizing radiation is well established; there is also a possible association with cancer at several other sites (rectum, lung, thyroid) Sont et al., 2001[211]. The only question that remains to be resolved with shipyard exposures is whether there is a detectable risk from the exposure which occurs both in those yards dealing with nuclear -powered vessels and from the work of industrial radiography. Detectable risk depends both on study design and factors such as sample size. Below a certain risk level no study will be big enough to demonstrate that risk in the population but that does not mean that individual cases of cancer will not arise caused by that exposure. The highest levels of exposure reported in shipyard studies (> 10 mSv of radiation) show some evidence of an association with an increased leukaemia risk (Kubale et al., 2005)[77] but other studies involving similar exposure levels failed to show similar effects. The level of risk which derives from shipyard exposures is clearly at the limit of detection of the studies carried out but the risk cannot be dismissed; thus if a worker exposed to ionizing radiation develops leukaemia then occupational exposure cannot be ruled out as the cause.

5.3 Painting, bladder and lung cancer

The risks of lung and bladder cancer are elevated in those employed as painters[190;212]; however the nature of the causative agent for these excess cancers remains a subject for speculation, with solvents, asbestos fillers, aromatic amines and chromate pigments proposed as the most likely candidates. Close working with asbestos products may be the strongest candidate for the lung cancer risk among painters. The known association of aromatic amines with bladder cancer in other contexts would tend to reinforce these as the strongest candidate for the causative agent associated with excess bladder cancer in painters.

5.4 Wood-working and nasal cancer

The association of nasal cancer with wood-working is supported by a number of studies and there has been some attempt to divide occupations where a risk is present from those where it may not be. However the occupation of wood-working in shipyards is not so precisely defined to discriminate those working with different types of wood. As a consequence of this general exposure to wood dust and considering the IARC (1995)[206] conclusion that all wood dust is potentially carcinogenic for humans no distinction is made in this review between the types of wood dust to which workers are exposed.

5.5 Conclusions regarding cancers associated with shipyard occupations

From the list of hazards in Table 13 a number have been explored in shipyard workers without any evidence of significant association or excess risk of cancer. The evidence for exposure to these hazards in shipyards is also rather limited and insufficient to draw any conclusions regarding the risks which may derive. Since there has been no evidence, from the epidemiological data, of an increased risk for the known associated cancer types in a potentially exposed group of shipyard workers no further detailed evaluation is made of the risk from the following hazards:

Benzene
Cadmium
Chromium (VI)
Coal tar pitch
EMF
Lead
Metal-working fluids
Nickel
Quartz
Solvents
Ultraviolet radiation (UVR) and skin cancer

This does not preclude the possibility that a worker or group of workers with a specific history of occupational exposure to any of these hazards may in consequence suffer from cancer which is due to that exposure.

Taking account of all of the information reviewed so far the following occupational cancer risks are considered to have been demonstrated in studies as relevant to shipyard workers. Other risks and associations may exist but so far they are not sufficiently demonstrated nor is there sufficient evidence for a definitive conclusion to be drawn.

The conclusions are drawn with the recognition that smokers have an excess risk of lung and bladder cancer compared with non-smokers. The conclusions are summarised in Table 14.

- The excess of lung cancer and mesothelioma seen in general in shipyard workers is concluded to be due primarily to exposure to asbestos which is proven to cause these cancers in humans.
- The association between exposure to asbestos fibers and laryngeal cancer is proven and as such laryngeal cancer among shipyard workers can be considered of occupational origin.
- Ionizing radiation is a known cause of human cancer over a wide range of exposures. The low exposures experienced in shipyards working with atomic-powered ships are concluded to carry a small but finite risk. Thus leukaemia occurring in workers with known ionizing radiation exposure may have an occupational origin.
- Those working as painters in shipyards are likely to carry the same risks as painters in other industries with some additional contribution from general asbestos exposure. Thus it is concluded that Lung and Bladder cancer in painters can be due to occupational exposures.
- The excess of lung cancer in welders has been explored in many studies without identification of a causative agent. The interaction of smoking and asbestos exposure has not been satisfactorily explained; it is concluded that lung cancer in welders may be occupationally related, but the causative agent is unknown.
- Ocular melanoma has been concluded to be linked to UVR exposure during welding and there is no reason to believe that shipyard welders would have any less risk than welders from other industries.
- The association of wood-working with nasal cancer is proven and thus this cancer in carpenters and wood-workers in shipyards is most likely to be due to occupational exposures.

Table 14

Cancers and causative agents linked to occupational exposures in shipyards

Occupational exposure	Cancer type	Causative agent
Asbestos	Lung, mesothelioma, larynx	Asbestos
Ionizing Radiation	Leukaemia	γ-Radiation
Painting	Bladder, Lung	Not known
Welding	Ocular melanoma	UVR
Wood-working	Sino nasal and naso-pharyngeal cancer	Wood dust

6. STRENGTH OF ASSOCIATION OF LINKED CANCERS

From this review some cancer risks have been identified from studies of shipyard workers. There are a range of known hazards in shipyards where risk has not been demonstrated but where it is considered likely that existing studies may have been unable to detect that risk. Table 15 brings all of these considerations together to conclude on the relevance of each for shipyard workers.

Table 15

Association of cancer types with occupation and exposure

Occupation relevance	Causative agent	Hazard identified and agreed	Shipyard exposure	Elevated risks in shipyard studies	Consistent finding	Relevant risk for shipyard workers.
Lung cancer						
All shipyard workers	Asbestos	IARC 1	Very high pre-1975	✓	✓	++
Sand-blasters	Quartz	IARC 1	No specific data but very likely	no specific shipyard data	✓strong evidence from other exposures	+
Welders	Nickel	IARC 1	Limited evidence	x	✓strong evidence from other exposures	±
Welders	Chromium (VI)	IARC 1	Limited evidence	x	✓strong evidence from other exposures	±
Painters	Coal Tar Pitch (as a paint pigment)	IARC 1	No specific data but very likely	no specific shipyard data	✓strong evidence from other exposures	±
Painters	Cadmium (as paint pigments)	IARC 1	No specific data but very likely	no specific shipyard data	✓strong evidence from other exposures	±
Painters	Unknown	IARC 1		no specific shipyard data	✓	+
Laryngeal cancer						
All shipyard workers	Asbestos	IARC 1	Very high pre-1970s	✓	✓	++
Mesothelioma						
All shipyard workers	Asbestos	IARC 1	Very high pre-1970s	✓	✓	++
Skin cancer						
Sheet metal worker, machinist	Metal working fluids	IARC 1	No evidence	no specific shipyard data	✓strong evidence from other industries	±

Table 15

Association of cancer types with occupation and exposure

Occupation relevance	Causative agent	Hazard identified and agreed	Shipyard exposure	Elevated risks in shipyard studies	Consistent finding	Relevant risk for shipyard workers.
Welders	UV radiation	IARC 1	No specific data but likely	no specific shipyard data	✓strong evidence from other industries	±
Uveal/ocular melanoma						
Welders	UV radiation	IARC 1 but no specific data related to welding	Likely but no evidence	no specific shipyard data	✓strong evidence from other industries	+
Leukaemia						
Nuclear workers and industrial radiographers	Ionizing radiation	IARC 1	Only for nuclear facilities and industrial radiographers	✓	✓	+
Painters	Benzene	IARC 1	Unknown but possible	no specific shipyard data	✓strong evidence from other industries	±
Sino-nasal and naso-pharyngeal cancer						
Wood workers	Wood dust	IARC 1	No specific data but very likely	✓	✓strong evidence from other industries	+
Bladder cancer						
Painters	Unknown	IARC 1	No specific data but very likely	no specific shipyard data	✓strong evidence from other industries	+

[#] Values are Risk estimate (95% CI)
++ strong evidence of a cancer risk for shipyard workers
+ Recognised cancer risk for shipyard workers
x Unlikely to be a cancer risk for shipyard workers
± possible cancer risk for shipyard workers but no evidence of exposure or increased cancer rates

It should be noted that the data that have been reviewed and many of the risks associated with shipyard occupations relate to practices that are no longer relevant. The conclusions of this review reflect current knowledge and relate particularly to the risks for cancer in those employed in shipyards between 1930 and 1980. Although many of the hazards remain, the reduced levels of exposure after 1980 and the consequent reductions in risk may not yet be evident in the database of studies reviewed.

6.1 Lung Cancer

A number of known human lung carcinogens were identified as potential hazards in shipyards. For some of these there is insufficient evidence either from exposure data or job-specific cancer rates to conclude about the risks in shipyards that might result. At best it may be concluded that the risk is not so far measurable among shipyard workers for Nickel, Chromium, coal-tar pitch or cadmium. This does not imply that there is no individual risk, since some individuals may experience such a level of personal exposure that a significant risk is present. Since a background risk of lung cancer is present for welders the additional risk from Nickel or Chromium exposure may have been too small to be detected in the studies conducted so far. Similarly for painters the causative agent for lung cancer risk has not so far been identified thus coal-tar pitch and cadmium may contribute a small component of the that risk.

For asbestos the risk is high and clearly defined and results from high levels of exposure over an extended period of shipyard operation. It is demonstrated that there is probably a linear relationship between cumulative exposure to asbestos and lung cancer rates lagged by about 10 years[57] although there is some indication that non-linear models provide a better fit to the data[53]. It is suggested by Hodgson & Darnton (2000)[53] that a best estimate excess lung cancer risk for chrysotile alone would be 0.1%/ fibre/cm^3.yrs[53], with a highest reasonable estimate of 0.5%/ fibre/cm^3.yrs[53] and that risks for the amphiboles are 10 to 50 times higher. A mixed exposure must be presumed to give risk levels somewhere between 0.1 and 5.0%/ fibre/cm^3.yrs. Review of additional data by Hodgson & Darnton (2010)[209] tended to confirm the value of 0.1%/ fibre/cm^3.yrs for excess risk of lung cancer and also suggested that the differences between risks from different types of asbestos may be smaller than previously proposed. Absolute risks are higher for smokers since the additional risk from asbestos exposure is at least additive with the additional risk arising from smoking[57]. The highest levels of exposure and therefore highest risk levels are likely to have occurred in jobs described as "laggers" and labourers but all shipyard workers, particularly those employed before 1970 may have had significant exposures to this known carcinogen.

Although Welders are stated by IARC[96] to have an additional risk of cancer of around 40%, compared with controls, the causative agent is not identified and the role of both asbestos and smoking in that excess cancer rate has not been clarified. A meta-analysis of available data by Moulin (1997)[124] gave an overall risk estimate of RR 1.30 (95% CI 1.14, 1.48) for shipyard welders, slightly lower than the IARC conclusion. Nevertheless there is general agreement that there is an excess of lung cancer in welders and this has been demonstrated to be true for shipyard welders[22] although the causative agent is not identified.

The exposure of sand-blasters to quartz is assumed for shipyards thus there is likely to be some risk deriving from that exposure to the known hazard. However the lack of data on exposure or any specific studies of shipyard workers exposed to quartz precludes any quantification of the likely risk.

Another category of worker at risk from lung cancer is painters. The hazard is agreed and formally recognised by IARC however the causative agents are not known, thus it is not possible to determine whether the exposures of painters occurring in shipyards carry a similar, smaller or

greater risk compared with those working in other industries. It can only be said that for an individual working as a painter there is an additional risk of lung cancer[190]. In a range of studies from various industrial sectors the Relative Risk (RR) of lung cancer, while statistically significant was generally 1.5 or lower and a recent meta-analysis[190] gave rates of 1.35 (95% CI 1.29, 1.41) for smokers and 2.00 (95%CI 1.09, 3.67) for non-smokers.

6.2 Mesothelioma

Mesothelioma arises almost exclusively as a consequence of asbestos exposure and incidence rates are demonstrated to have a linear relationship with cumulative dose but with a lag period of around 40 years[57] but valid for up to 50 years since last exposure. Incidence rates for this cancer do not appear to be affected by the smoking habit or smoking history of the individual. Any occurrence of this cancer in an individual with a history of working in shipyards would be most likely to be related to occupational exposure but those in occupations such as "laggers" and labourers probably had the highest exposures and consequently the highest risks. As an illustration of rates in non-asbestos workers Krstev et al., (2007)[22] reported SMR values of 14.53 (95% CI 1.63, 52.47) for electricians and 16.65 (95% CI 1.87, 60.12) for sheet-metal workers but it should be noted that these are based on very small numbers. Although mesothelioma risk increases with exposure small doses or short duration of exposure to amphiboles (amosite and crocidolite) can lead to development of mesothelioma.

6.3 Laryngeal cancer

Laryngeal cancer has been linked with strong human evidence to occupational exposure to asbestos fibers. It has been established that potentially all shipyard workers may have been exposed to asbestos and as such, laryngeal cancer must be considered as an occupational risk for shipyard workers. However the direct evidence is scanty and only based on mortality data; as laryngeal cancer has a good survival rate, incidence data would have been more pertinent. Thus one study (Puntoni et al., 2001) [45] reported a statistically significantly increased overall SMR of 1.64 (95% CI 1.12, 2.32). Another shipyard workers study (Krstev et al., 2007)[22] reported a non significant increased SMR of 1.56 (95% CI 0.92, 2.46).

6.4 Skin Cancer and ocular melanoma

UV irradiation is known from general population studies to have a potential to cause skin cancer of various types. Occupational exposure of significance in shipyards is that of welders. Arc welding produces the full spectrum of UVR, including UVB. It is therefore likely that welders will be exposed to a greater risk of skin cancer than the rest of the population if they do not protect skin. Nevertheless, evidence about whether the UVR from arc welding is causing skin cancer is minimal and the risk cannot be quantified.

The same exposure as above has been shown to be associated with an increased risk of ocular melanoma, however there is no evidence that this has occurred in shipyard workers.

Some metal-working fluids (poorly-refined oils) have been demonstrated and agreed to be human skin carcinogens. No studies were identified of shipyard workers exposed to these products or any excess of skin cancer being attributed to shipyard use of such products therefore the risk cannot be quantified.

6.5 Leukaemia

Two established causes of leukaemia are known hazards present in some shipyards, benzene and ionizing radiation exposure.

Although benzene as a solvent has been used historically by painters, regardless of place of employment, the evidence for specific exposure of shipyard painters does not exist. The lack of any epidemiological evidence of increased risk of leukaemia among those employed as painters suggests that exposures may not have been sufficient to cause a detectable incidence of leukaemia. If there is specific evidence for the exposure of an individual to benzene (i.e. employed as a painter between pre-1980) then an occupational link cannot be ruled out. Otherwise it is unlikely that a significant risk is present relative to shipyard painters or other workers.

Ionizing radiation is proven to cause leukaemia at a rate proportional to cumulative radiation dose; in the analysis of a single data set using a linear model the additional risk per 10 mSv is concluded to be ERR 1.9% (95% CI -0.9%, 6.6%). The hazard is clearly present in all shipyards dealing with nuclear powered vessels and in the occupation of industrial radiographer. Although the populations exposed and the risk levels are very low the studies available generally support the presence of a low level of risk of leukaemia at some of the exposure levels recorded in shipyards. The incidence rates for the lowest exposure groups are at or around the level of detection of the studies thus conclusions of different analyses are sometimes contradictory. This is one category of exposure which is considerably better documented than others and since the accumulated exposure is directly related to risk each case can be independently assessed for occupational relevance.

6.6 Sino-nasal and naso-pharyngeal cancer

The association of wood-working with nasal cancer is proven and exposure in shipyards is inevitable for those working as wood-workers and carpenters. The exposure levels in shipyards are not documented but assuming the need on occasions to work in confined spaces it is likely that exposures are at the higher end of those for wood-workers in general. There is limited evidence that shipyard wood-workers have a higher risk of cancer (Krstev et al., 2007)[22] but it is concluded that a significant risk is likely for this group.

6.7 Bladder cancer

Bladder cancer is recognised to be an occupational hazard by the IARC classification of painter as an occupation involving carcinogenic exposures. Since the specific causative agent is unknown there can be no assessment of exposure however the occupation itself carries a risk which must be considered to apply also to painters in shipyards. The magnitude of that risk is not certain since painting in confined spaces may give a different exposure profile from that of other painters, however a meta-analysis of studies of bladder-cancer among painters[191] after adjustment for smoking indicated a RR of 1.28 (95% CI 1.15, 1.43). Another meta-analysis[192] gave figures very much in the same region.

6.8 General Conclusions

The detailed review and analysis of the data on cancers relevant to shipyard working indicate the major risk for all shipyard workers to be lung and pleural cancer as a result of asbestos exposure. Job categories particularly affected by this include lagers, pipefitters and labourers; however the evidence indicates that all shipyard workers are at risk.

Most of the studies relate to workers, who were mostly employed prior to improvements in occupational hygiene controls. While conclusions are relevant for those workers the risks may be overestimated for workers with more recent history of shipyard employment and a subsequent lower exposure to the identified hazards.

Other job-specific risks are identified for painters, wood-workers, sand-blasters and welders but the data available provide a very limited base for any quantification of risk.

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ANNEX 1- RETRIEVAL OF REFERENCES

The following describes the search strategy used by the IRSST to retrieve the original set of references which form the basis of this review.

PUBMED

Epidemiologic Studies[MESH] OR epidemiologic[TIAB] OR Epidemiological[TIAB] OR epidemiology[TIAB] OR Case-Control[TIAB] OR Cohort[TIAB] OR Cross-Sectional[TIAB] OR Meta-Analysis[TIAB] OR Meta-Analysis[Publication Type]
AND
shipyard*[TIAB] OR ship[TIAB] OR ships[TIAB] OR ships[MESH]
AND
cancer*[TIAB] OR neoplasm[TIAB] OR neoplasms[TIAB] OR Neoplasms[MESH]

+

Labourer*[TIAB] OR Maintenance[TIAB] OR Burner*[TIAB] OR Steel worker[TIAB] OR Pipefitter*[TIAB] OR Sheet metal worker[TIAB] OR Crane operator[TIAB] OR Electrician*[TIAB] OR Painter*[TIAB] OR Rigger*[TIAB] OR Joiner*[TIAB] OR Oiler*[TIAB] OR Greaser*[TIAB] OR Welder*[TIAB] OR sandblast*[TIAB] OR blazing[TIAB] OR soldering[TIAB] OR buffing[TIAB] OR welding[TIAB] OR grinding[TIAB] OR Metal grinding fluid*[TIAB] OR Metal cutting fluid*[TIAB] OR EDM fluid*[TIAB] OR Machining fluid*[TIAB] OR Metalworking fluid*[TIAB] OR Cutting fluid*[TIAB]
AND
Epidemiologic Studies[MESH] OR epidemiologic[TIAB] OR Epidemiological[TIAB] OR epidemiology[TIAB] OR Case-Control[TIAB] OR Cohort[TIAB] OR Cross-Sectional[TIAB] OR Meta-Analysis[TIAB] OR Meta-Analysis[Publication Type]
AND
cancer*[TIAB] OR neoplasm[TIAB] OR neoplasms[TIAB] OR Neoplasms[MESH]

OSH UPDATE

Labourer* OR Engine Fitter OR Maintenance mechanic OR Burner* OR Steel worker OR Pipefitter* OR Sheet metal worker OR Crane operator OR Electrician* OR Painter* OR Rigger* OR Joiner* OR Oiler* OR Greaser* OR Welder* OR sandblast* OR waterblast* OR blazing OR soldering OR buffing OR welding OR grinding OR Fluide* de coupe OR Metal grinding fluid* OR Metal cutting fluid* OR EDM fluid* OR Machining fluid* OR Metalworking fluid* OR Cutting fluid* / All fields
AND
cancer* OR Neoplasm* / All fields
AND
Epidemiologic OR Epidemiological OR epidemiology OR Case-Control OR Cohort OR Cross-Sectional / All fields
NOT
Construction OR building*

+

Epidemiologic OR Epidemiological OR epidemiology OR Case-Control OR Cohort OR Cross-Sectional
AND
shipyard* OR ship*
AND
cancer* OR Neoplasm*

CCHST

((sandblast* OR waterblast* OR blazing OR soldering OR buffing OR welding OR grinding OR Fluide* de coupe OR Metal grinding fluid* OR Metal cutting fluid* OR EDM fluid* OR Machining fluid* OR Metalworking fluid* OR Cutting fluid*OR Labourer* OR Engine Fitter OR Maintenance mechanic OR Burner* OR Steel worker OR Pipefitter* OR Sheet metal worker OR Crane operator OR Electrician* OR Painter* OR Rigger* OR Joiner* OR Oiler* OR Greaser* OR Welder*) AND (cancer* OR Neoplasm*)) NOT (Construction OR building*)

+

(shipyard* OR ship*) AND (cancer* OR Neoplasm*)

TOXLINE

(Labourer* OR Engine Fitter OR Maintenance mechanic OR Burner* OR Steel worker OR Pipefitter* OR Sheet metal worker OR Crane operator OR Electrician* OR Painter* OR Rigger* OR Joiner* OR Oiler* OR Greaser* OR Welder*) AND (cancer* OR Neoplasm*) AND (epidemiologic*)

+

(Epidemiologic OR Epidemiological OR epidemiology OR Case-Control OR Cohort OR Cross-Sectional) AND (shipyard* OR ship*) AND (cancer* OR Neoplasm*)

ISST

(sandblast* OR waterblast* OR blazing OR soldering OR buffing OR welding OR grinding OR Fluide* de coupe OR Metal grinding fluid* OR Metal cutting fluid* OR EDM fluid* OR Machining fluid* OR Metalworking fluid* OR Cutting fluid*) AND (cancer* OR Neoplasm*)) NOT (Construction OR building*)