Controlling fumes and ultraviolet radiation exposure from welding and minimising the associated risk of cancer – review of published evidence

Final report

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BACKGROUND OF THE AUTHOR

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GLOSSARY

BP	Boiler plate
FCAW	Flux cored arc welding
GM	Geometric mean
GMAW	Gas metal arc welding
gsd	Geometric standard deviation
GTAW	Gas tungsten arc welding
IARC	International Agency for Research on Cancer
IQ	Inter-quartile range
LOD	Level of detection
MAG	Metal active gas
Med	Median
MIG	Metal inert gas
MMAW	Manual metal arc welding
MS	Mild steel
n.d.	Not detected
PPE	Personal protective equipment
ppm	Parts per million
sd	standard deviation
SMAW	Shielded metal arc welding
SS	Stainless steel
TIG	Tungsten inert gas

OVERVIEW

BACKGROUND

- Welding is very common in Australian workplaces.
- Welding fumes cause lung cancer and ultraviolet radiation from welding causes melanoma of the eye.
- WorkSafe Victoria wanted an up-to-date understanding of the current literature on welding fume and controls available for welding fume and welding ultraviolet radiation in order to inform a range of activities designed to prevent and control any ill health arising from welding activity.

Aim: To provide a detailed review of the epidemiological and occupational hygiene literature

Peer-reviewed and grey literature

150 relevant papers identified, summarised and critically appraised

Study methodologies

Key methodological issues and challenges in studies considered

Very little usable Australian data

Opportunity to fill current data gaps

FINDINGS

Welding

Welding fumes often above occupational exposure standard

Often above occupational exposure standard

Main influences:

- Welding type
- Flux composition
- Consumable electrode type
- Material type being welded
- Presence and type of coating
- Strength of current used
- Ventilation and air flow
- Space where welding is conducted
- Position of welder's head in relation to fume plume
- Use of helment or respirator

Comparison of factors

Type of welding

Lowest exposure with gas tungsten arc welding
Highest exposure tend to be with flux cored arc welding

Local exhaust ventilation usually better than general

On-gun extraction probably most effective form when used properly

Purified Air Powered Respirators provide excellent control

Will sometimes be needed despite other controls

UV radiation

Excessive exposure

Can occur in only a few minutes of welding

Auto-darkening visors

Strongly recommended for use when welding

Goggles

Should be worn at all times, even when not welding

RECOMMENDATIONS

It is recommended that WorkSafe Victoria:

- consider how it might obtain information on current welding fume exposure levels in Victorian workplaces
- strongly encourage the use of purified-air powered respirators by welders in most situations during welding
- strongly encourage the use of goggles by all welders, and other workers in the vicinity, when welding is being undertaken
- strongly encourage the use of auto-darkening visors and for these to be worn before the welding arc is started
- make the information in this report available to workers and employers in workplaces where welding takes place.

EXECUTIVE SUMMARY

Background

Welding is very common in Australian workplaces with probably several hundred thousand workers undertake welding in some form. However, welding fumes cause lung cancer and ultraviolet radiation from welding causes melanoma of the eye. Therefore, WorkSafe Victoria wanted an up-to-date understanding of the current literature on levels of welding fume, and controls available for welding fume and welding ultraviolet radiation, in order to inform a range of activities designed to prevent and control ill health arising from welding activity.

Aim

The formal aim of the project was to provide a detailed review of the epidemiological and occupational hygiene literature regarding:

- exposure levels associated with welding
- the various control methods that might be appropriate
- the levels of exposure likely to be associated with these prevention control methods (where possible).

Approach

The report used information in the peer-reviewed literature, supplemented by a small amount of information from the grey literature. The report covered the few relevant review articles but also considered the relevant single studies. Studies were identified through a comprehensive search of the published literature. The studies were critically appraised, the findings summarised and their relevance to the Australian context considered. The key methodological issues and challenges in the studies were also considered.

Findings

About 150 relevant papers were identified, summarised and critically appraised.

The main factors that influence the amount, nature and composition of welding fume appear to be the welding type, composition of the flux, type of consumable electrode, type of material being welded, the presence and type of coating on the material being welded and the strength of the current used. The amount of fume that reaches the breathing zone of the worker is influenced by all these aspects, as well as by aspects such as the use of ventilation, the air flow, the space in which the welding is being done (confined, indoors or outdoors), the position of the welder's head in relation to the fume plume and the use of helmet or respirator.

A range of measures are suitable to control exposures, and many should apply in the vast majority of welding circumstances. The evidence suggests that in many circumstances LEV or on-tool extraction will be sufficient to produce acceptable levels of total fume and individual contaminants. However, there are also many circumstances where this will not be the case or where the ventilation is not available or is not used. Also, the evidence suggests that in many workplaces in other countries, exposure to welding fume is often above the relevant occupational exposure level. It is not known if that is also the case in Australian workplaces but there is good reason to consider it might be given the similarities in work practice compared to Australia in many of the countries in which the studies were based. In such circumstances, it is important that welders use properly fitted respirators. In terms of being effective and practical, the most appropriate type of respirator seems to be purified-air powered respirators. Powered air supply respirators are also very effective but are less practical and not usually able to be used in outdoor settings. When used properly, both these approaches should control exposures of welders to well below the exposure standard and should minimise the risk of welders developing lung cancer as a result of exposure to welding fume. Information available from the literature on the effectiveness of exposure control measures is summarised in the table below.

Control measure	**Decrease in fume**
Welding type (compared to Flux cored arc welding (FCAW))	
Gas metal arc welding (GMAW)	71%
Gas tungsten arc welding (GTAW)	94%
Manual metal arc welding (MMAW)	85%
Ventilation (compared to no ventilation)	
Mechanical	68%
Local exhaust ventilation	10% - 63%
Welding gun extraction	64%
Purified air powered respirator	93%

An important finding of a number of the studies was that it is not just welders who risk being exposed to concerning levels of fume and the associated increased risk of developing lung cancer. Persons working in the same general area where welding is undertaken may also be exposed, necessitating the use of effective control measures relevant to all workers, such as separating workers from the welding area by distance and by physical barriers (such as welding curtains) and having effective general ventilation and fume extraction in the workplace.

The main factors that appear to influence the levels of ultraviolet radiation associated with welding appear to be the workplace design, the type of welding, the shielding gas and the type of flux and electrode. The main determinant of the amount of ocular ultraviolet radiation exposure to the welder, apart from the length of time welding, is the use of an appropriate face shield. The evidence strongly supports using auto-darkening visors. The short period (sometimes less than a minute) of unprotected exposure allowable before limits are exceeded strongly suggest that welders, and others in the workplace where welding is occurring, should wear suitable goggles at all times. If this does not occur, it is difficult for welders to adequately protect themselves from ultraviolet radiation exposure arising from the welding of other workers, even if they diligently wear appropriate eye protection when they are welding. As with the findings in regards to fume, perhaps even more so, there is a need to protect other persons working in the vicinity of welders from exposure to ultraviolet radiation. Separating workers from the welding area by distance and by physical barriers (such as welding curtains) and ensuring other workers wear appropriate goggles to protect from ultraviolet radiation, is very important to decrease the risk of ocular melanoma (and other disorders related to ultraviolet radiation exposure).

Conclusion

This report has met the main aim of the study – to provide a detailed review of the epidemiological and occupational hygiene literature regarding exposure to fume and ultraviolet light arising from welding and associated control methods. There was a reasonable amount of information about welding fume exposure in general, but almost no published information about this for Australia. There was also a limited amount of information about how absolute exposure levels in real-world settings change with different control measures, but what information is available has been summarised. The findings of the report should assist WorkSafe Victoria in providing appropriate up-to-date advice on control measures used to decrease the risk of cancer arising as a result of exposures associated with welding. WorkSafe Victoria should consider how they might obtain information on current welding fume exposure levels in Victorian workplaces as these would be useful supplements to the information available from the published literature.

It is recommended that WorkSafe Victoria:

- consider how it might obtain information on current welding fume exposure levels in Victorian workplaces, as this would usefully supplement the information currently available from the published literature
- strongly encourage the use of purified-air powered respirators by welders in most situations during welding
- strongly encourage the use of goggles by all welders, and other workers in the vicinity, when welding is being undertaken
- strongly encourage the use of auto-darkening visors and for these to be worn before the welding arc is started
- make the information in this report available to workers and employers in workplaces where welding takes place.

1. INTRODUCTION

Welding is a very common work activity. In 2017, the International Agency for Research on Cancer (IARC) classified welding fume as an IARC Group 1 ('carcinogenic to humans) carcinogen, with the relevant outcome being lung cancer. At the same time, IARC classified ultraviolet radiation from welding as an IARC Group 1 carcinogen, with ocular melanoma as the relevant outcome. There are also a range of other adverse health outcomes associated with welding. This emphasises the importance of having good control of exposures that might arise from welding. WorkSafe Victoria (WorkSafe) required an up-to-date understanding of the current literature on controls available for welding fume and welding ultraviolet radiation in order to inform a range of activities designed to prevent and control any ill health arising from welding activity. In particular, WorkSafe wanted to "*to better understand the exposure risk during a range of welding activities, and increase industry knowledge of requirements for the prevention of exposure and control of risk from welding fume and UV radiation.*". This project was designed to provide a detailed summary of relevant literature to support this planned activity by WorkSafe Victoria.

In particular, the research aimed to explore what reasonably practicable controls employers can implement, e.g. ventilation, isolation through shielding, on tool extraction, to ensure employees are not exposed to risk during welding activities. It also sought to identify the expected exposure to welding fume (mg/m^3 over 8 hr time weighted average) when using each identified control method.

This report provides a consideration of the more recent epidemiological and occupational hygiene literature regarding control measures used in welding. The agreed focus of the review was peer-reviewed published literature, with some supplementation by articles from the grey literature, primarily where there was little identified peer-reviewed literature. It primarily considered publications from 2000 onwards, but general exposure information back to 1990 was covered. The intended focus was on review articles, but as there were few of these, many individual studies were also considered.

The project focussed on cancer-related exposures – fume and UV radiation. There are a several other hazards associated with welding. These include noise, heat, electric current, fire and explosion. An overview of control measures relevant to these hazards can be found elsewhere[1].

This report consists of eight chapters:

- Chapter 1 provides a brief introduction
- Chapter 2 outlines the methods used
- Chapter 3 presents a summary of the results of the literature review process and an introduction to welding
- Chapter 4 presents a review of relevant literature in regards to welding fume
- Chapter 5 presents a review of relevant literature in regards to ultraviolet radiation
- Chapter 6 provides a consideration of the methods used in the project and other aspects of the review process, and their implications for the report's findings
- Chapter 7 provides a brief conclusion
- Chapter 8 contains the references cited in the document.

There is also one appendix, which provides some additional detail on the literature search.

2. METHODS

INTRODUCTION

This section summarises the methods used in this study. Additional information on the search strategy and its output are provided in Chapter 3 and Appendix 1.

INCLUDED DATABASES

The main searches were undertaken in Medline (via Ovid) and Scopus. Some additional targeted searches for individual articles were conducted using PubMed. A search of the grey literature was also undertaken, focusing on formal reports from public agencies.

SEARCH STRATEGY

Separate search strategies were developed for each database and exposure type, but they all used the same general approach. The approach was to identify all review articles and individual articles that contained information on exposure to welding fume or ultraviolet radiation and on control measures used in welding. Searches were undertaken in each database to cover each of the main control measures, particularly ventilation, on-tool extraction and personal protective equipment (PPE). For the initial search, publications were limited to those papers published since the beginning of 2000. Only studies of humans were included. The final searches were conducted in May and June of 2020. In addition to the database search, the reference list of included papers was reviewed to identify any possibly relevant papers not identified by the database searches. For the general welding exposure information, publications back to 1990 were included.

INCLUSION AND EXCLUSION CRITERIA

The main inclusion criteria were full publications of peer-reviewed studies that provided information on, or relevant to, exposures to welding fume and ultraviolet radiation or control measures used in welding. Excluded were:

- Studies that only provided information on adverse health effects associated with welding
- In vitro studies
- Studies that did not focus on humans.

Review process

Studies identified through searching either of the included databases were combined into one EndNote file.

First, based on title and author, duplicate studies were deleted. Next, based on title and abstract, studies that did not meet the search criteria were excluded. The full text version of studies that appeared to meet inclusion criteria, or for which there was some uncertainty, was examined and a final decision then made on inclusion or exclusion. For studies identified through review of reference lists the full text version was also examined and a final decision made regarding inclusion or exclusion. A search of Medline using PubMed was undertaken where specific single studies were sought. Any additional studies identified through the PubMed searches were added to the main EndNote file.

One person (the author) undertook all the searching and made all decisions regarding inclusion and exclusion.

Data extraction, critical appraisal and synthesis

The author critically appraised all included studies, considering for each the study aims, methodology and key results and identifying the key strengths and limitations of the methodology and the potential effect of the identified limitations on the study findings.

The results from the included studies were summarised and/or synthesised qualitatively, with separate synthesis undertaken by control measure. The common strengths and limitations of the included studies were also considered and described.

3. RESULTS - OVERVIEW

INTRODUCTION

This chapter provides a brief overview of the mechanistic aspects of the literature search and some general information on welding. The next two chapters provide a consideration of the relevant data from the included papers for welding fume and for ultraviolet radiation exposure arising from welding. The presented consideration of the literature intended to focus on obtaining review articles (systematic and narrative reviews), but as there were few of these, many individual studies were also considered.

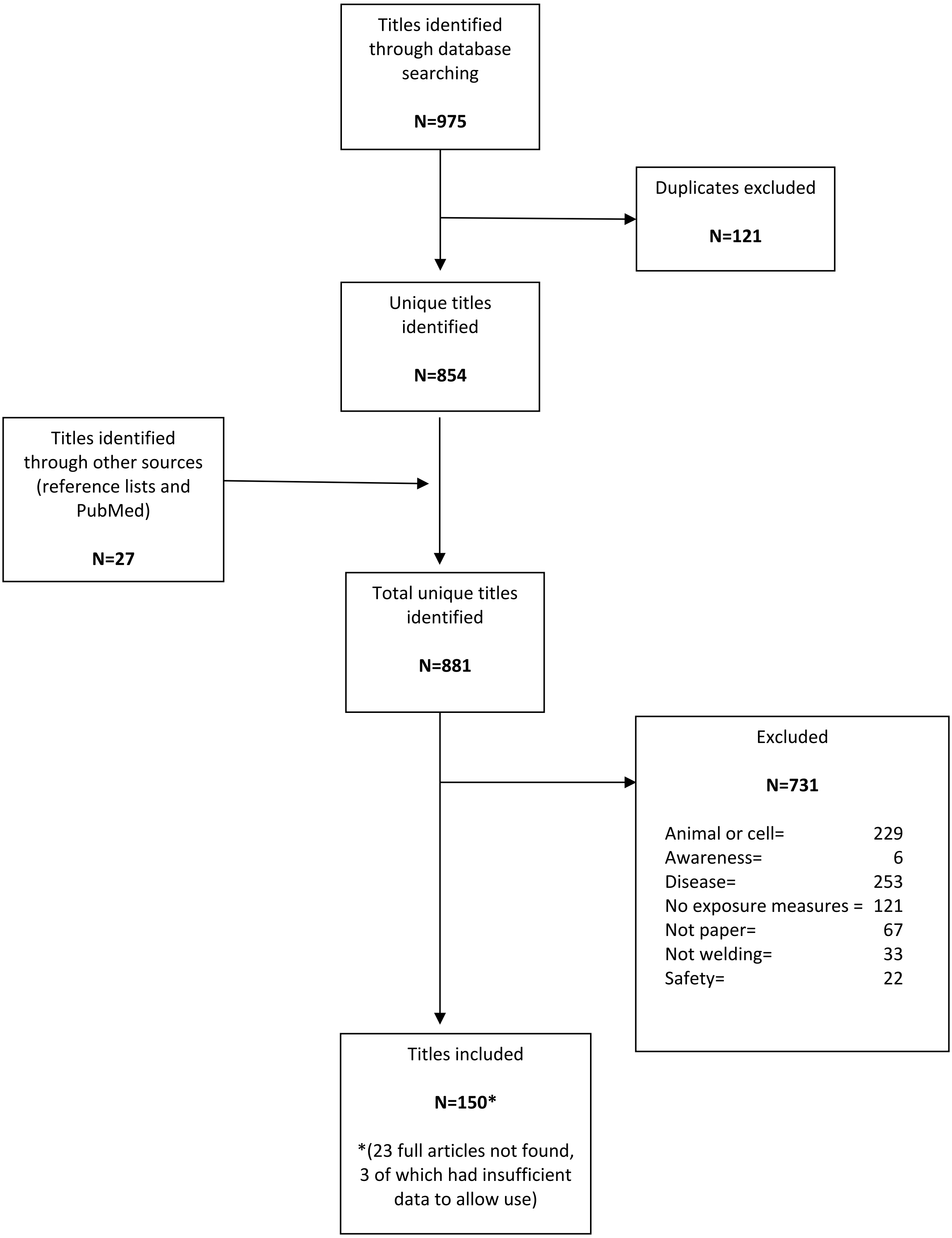
OUTCOME OF THE LITERATURE SEARCH

Nine hundred and seventy-five titles were identified in the combined searches. One hundred and twenty-one of these were excluded as they were duplicates, leaving 854 unique titles. Twenty-seven articles were identified through review of reference lists or through separate searches for individual studies, resulting in 881 titles for review. Of these, 731 were excluded on the basis of title, abstract or full text. That left 150 relevant papers. The full papers for all but 23[2-24] of these were obtained, and for all but three[11, 14, 16] of those for which the full paper was missing there was sufficient information in the abstract or other papers to allow their information to be considered (Figure 1). Fifty-two of the papers were on laboratory-based studies, 52 were on field studies, six were narrative reviews and five were systematic reviews. Another 22 were overviews of areas with limited citing of formal research papers, and the remainder had an uncertain format (9) or were in some other format (4).

WELDING IN AUSTRALIA

There is no reliable publicly available information on the number of workers in Australia involved in welding, but it is likely to be at least several hundred thousand. Welding is a feature of many different occupations, not just for workers formally employed as welders. Globally, it is estimated that at least 10 million workers undertake welding tasks[25]. Many more workers will be exposed as bystanders[26, 27].

Figure 1: Flow chart of study identification and selection (results from Medline and SCOPUS)



WELDING OVERVIEW

Welding is "*the process of joining two pieces of metal permanently by means of heat, pressure or both*"[28]. A recent review provides a good summary of the welding process: "*Welding is a metal joining process that uses heat and/or pressure. There are allied processes of cutting, brazing, and soldering, which are often grouped along with welding. The welding process is usually classified into two main groups, i.e., gas welding and arc welding…. In turn arc welding is categorised into two sub-groups, i.e., metal arc welding such as shielded metal arc welding (SMAW), also known as manual metal arc welding (MMAW), and gas shielded arc welding such as gas metal arc welding (GMAW), flux cored arc welding (FCAW), gas tungsten arc welding (GTAW), also known as tungsten inert gas welding (TIG), and metal inert gas (MIG) welding. Typically, the inert gases used for MIG welding are argon or helium. Metal active gas (MAG) welding is a similar process that uses a reactive gas condition, also known as 'shielded with an active gas'; CO_2 is mainly used as the shielding gas in this process. More than 90% of steel used in welding are mild steels, carbon steels or low alloy steels, with the remainder being stainless steel. Welding can also be carried out on aluminium [aluminium], titanium, nickel or other metals.*"[29].

The welding process produces fumes when the heated material vapourises and then solidifies into small particles. The resultant fume can contain any of a number of different potentially harmful constituents, mainly metals, including in particular chromium (VI), copper, iron, manganese, nickel and zinc; a range of gases such as ozone, carbon dioxide, carbon monoxide and oxides of nitrogen; and various components of the range of fluxes used and the coatings on the metals being welded[29-32].

As mentioned, welding fume has been classified by IARC as a known human carcinogen (Group 1), with lung cancer being the outcome of concern, although there is also limited evidence that exposure to welding fume may increase the risk of developing kidney cancer[25, 33]. Another exposure of concern is the ultraviolet radiation associated with welding. This has also been classified by IARC as a known human carcinogen, causing ocular melanoma[33]. Welding has also been associated with a range of other health disorders, most particularly parkinsonism, chronic obstructive pulmonary disease, burns, eye injuries and corneal epithelial damage and noise-induced hearing loss[34].

Skin cancer in welders

There has been concern about skin cancer in welders because of the known connection between exposure to some forms of ultraviolet radiation and increased risk of melanoma of the skin and non-melanoma skin cancer[35], and the known potential for welders to have skin exposure to ultraviolet radiation from welding. However, the evidence for increased risk of skin cancer in welders is not strong. In the most recent relevant review, Falcone and Zeidler-Erdely conducted a narrative review of relevant studies published up to October 2017. They cited five studies, noting a number of methodological limitations of the studies, including incomplete control of confounding, (they mentioned *"…radiation from other sources, time spent outdoors, length of time welding and type of welding performed, as well as personal factors such as family history of skin cancer, skin type, and use of personal protective equipment (PPE) and sunscreen…"*). Their main conclusion was that "*…a definitive link between welding and increased risk of skin cancer cannot be proven at this time.*"[36].

An earlier, brief, narrative review examining the evidence of an increased risk of skin cancer and ocular melanoma arising from ultraviolet radiation exposure associated with welding included studies published to December 2003. Only one relevant study was identified, and this did not show any evidence of an increased risk. The authors noted methodological limitations of the study, including probable low exposures (meaning exposures may have been insufficient to produce an identifiable increase in risk) and the young age of subjects (which might mean there was insufficient follow-up to identify an increased risk)[37].

In summary, published studies do not provide strong evidence of an increased risk of skin cancer (melanoma or non-melanoma) as a result of exposure to ultraviolet radiation from welding. There are not many relevant studies; all the identified studies have important potential methodological limitations which could have led to overestimation or underestimation of any risk arising from exposure; and those studies that did provide formal risk estimates provided little or no evidence the risk was elevated. Nevertheless, it seems prudent for welders, and other workers in the vicinity of welding, to cover exposed skin to the extent reasonably possible whilst welding is being conducted.

4. RESULTS – WELDING FUME

INTRODUCTION

This chapter provides consideration of the relevant data from the included papers for welding fume.

WELDING FUME OVERVIEW

As mentioned, welding fume has been classified by IARC as a known human carcinogen (Group 1), with lung cancer being the outcome of concern, although there is also limited evidence that exposure to welding fume may increase the risk of developing kidney cancer[25, 33]. The increased risk appears to arise both from welding stainless steel and from welding mild steel[38]. The current workplace exposure standard (eight hour time-weighted average) for welding fume in Australia is 5 mg/m^3 (or 3.5 mg/m^3 for a 12-hour work day)[39].

The health concerns associated with welding fume have prompted the use of a range of control mechanisms. Following the approach of the hierarchy of control, these include isolation and workplace design; a range of engineering approaches, particularly various forms of ventilation and shielding; work practices; and the use of PPE, particularly respirators and visors. Several review articles have considered in reasonable detail the literature relevant to one or more of these control measures[29, 31, 40], and there are many general papers which provide good overviews of various aspects of hazard control[15, 41-52], as well as codes of practice[1]. The remainder of this chapter considers the published evidence about exposure levels of welding fume and gases, the most important influences on welding fume, and the associated relevant control measures.

EXPOSURE LEVELS OF WELDING FUME AND GASES

The identified information on levels of welding fume and gases from studies of workplaces is shown in Table 1 (total fume), Table 2 (selected metal constituents) and Table 3 (gaseous constituents). The data are the arithmetic mean and range of measurements of total welding fume taken in the breathing zone unless otherwise specified, with information on country, year of publication, welding type and material being welded also provided.

Table 1. Summary of measurements of total welding fume (mg/m³).

Place	Circumstance	Type*	Mean (mg/m³)^	Range (mg/m³)#
Denmark, 1990[53]	Construction	MMAW-MS GTAW-SS	4.7 1.3	
Netherlands, 1990[54]	Various	FCAW-MS GMAW-MS MMAW-MS FCAW GMAW-SS GTAW-SS MMAW-SS	4.0 4.6 4.6 5.9 1.3 11.3	2.9-6.8 1.5-14.2 1.0-11.0 1.0-19.4 0.7-3.3 2.1-41
Denmark, 1991[55]	Manufacturing	(GMAW+MMAW)-MS GTAW-SS	3.1 0.94	1.7 (sd) 0.83 (sd)
New Zealand, 1991[24]	Various	GMAW-MS GTAW-SS	2.56 0.63	0.93-4.19 0.33-1.28
Denmark, 1992[56]	Manufacturing	GMAW-SS GTAW-SS (GTAW + MMAW)-SS	1.01 0.98 0.96	
England, 1992[57]	Shipyard	MMAW-MS	4.39	
Finland, 1992[58]	Shipyard	MMAW-MS	11.8	3.4-19.2
Poland, 1993[@59]	Manufacturing Chemical plant Industrial plant Industrial plant	MMAW-SS MMAW-SS MMAW-SS MMAW-SS	9.0 3.2 3.5 1.3	2.8-23.4 1.0-9.1
Norway, 1994[60]	Shipyard: - Ship-section - Platform - Welding shop	 MMAW-SS MMAW-SS MMAW-SS	 5.4 3.0 2.0	 0.3-29 1.0-5.8 0.5-6.6
U.S., 2000[32]	Construction	GMAW, GTAW, MMAW	5.78 4.12	<1.020–37.290 0.100–18.040
U.S., 2001[61]	Manufacturing	FCAW-SS	7.15	2.2-16.1
U.S., 2001[62]	Manufacturing	FCAW-BP GMAW-SS GTAW-SS	8.97 1.61 0.16	1.17-55.5 0.49-2.67 0.06-0.27
Poland, 2002[63]	Manufacturing	GMAW-Al (total) GTAW-Al (total) GMAW-Al (respirable) GTAW-Al (respirable)	6.0 0.69 2.6 0.79	0.8-17.8 0.25-1.36 0.7-6.0 0.32-1.85
U.S., 2002[64]	Construction	MMAW-MS	9.33	?-21.1

Table 1. Summary of measurements of total welding fume (mg/m^3) continued.

Place	Circumstance	Type*	Mean (mg/m^3)^	Range (mg/m^3)#
New Zealand, 2004[65]	Engineering	(GMAW + GTAW)-SS - Factory 1 - Factory 2 - Factory 3 - Factory 4	 0.91 0.50 2.12 5.28	
Poland, 2004[66]	Industrial	FCAW		0.2–24.3
U.S., 2007[67]	Construction	MMAW-CS (no vent) MMAW-CS (with vent)	5.60 4.55	2.65–11.6 3.15–5.44
U.S., 2009[68]	Boiler repair	MMAW-CS	4.73	3.62-5.06
Saudi Arabia, 2010[69]	Manufacturing	MMAW-MS – All MMAW-MS – Factory 1 MMAW-MS – Factory 2 MMAW-MS – Factory 3 MMAW-MS – Factory 4 MMAW-MS – Factory 5 MMAW-MS – Factory 6	6.5 6.3 5.3 11.3 6.8 4.7 3.0	1.0-57.5 4.0-18.0 4.5-14.0 6.5-57.5 5.5-13.5 1.0-14.0 1.5-5.0
U.S., 2011[27]	Manufacturing	GMAW-MS GTAW-MS MMAW-MS	0.510 0.630	0.140-1.700 0.046-0.077 0.150-2.100
Germany, 2012[70]	Manufacturing	Inhalable-MS/SS All FCAW GMAW GTAW MMAW Respirable-MS/SS All FCAW GMAW GTAW MMAW	 1.51 (med) 8.02 (med) 3.65 (med) <0.58 (med) 1.12 (med) 1.29 (med) 7.11 (med) 2.08 (med) <0.42 (med) <0.49 (med)	 <0.65, 4.50 (IQ) 2.83, 12.05 (IQ) 1.80, 5.69 (IQ) <0.42, 0.93 (IQ) 0.52, 3.55 (IQ) <0.45, 4.01 (IQ) 4.53, 10.10 (IQ) 1.20, 3.78 (IQ) <0.36, <0.51 (IQ) <0.45, 1.85 (IQ)
Germany, 2012[71]	Manufacturing	Inhalable-MS/SS All FCAW GMAW GTAW Respirable-MS/SS All FCAW GMAW GTAW	 1.12 (med) 6.24 (med) 2.71 (med) 0.56 (med) 0.97 (med) 6.87 (med) 1.64 (med) n.d. (med)	 0.46, 3.73 (IQ) 1.05, 12.40 (IQ) 0.74, 5.02 (IQ) <LOD, 0.93 (IQ) n.d.,3.42 (IQ) 3.36, 10.1 (IQ) n.d., 3.34 (IQ) n.d., 0.46 (IQ)
Iran, 2012[72]	Construction – gas pipelines	MMAW-iron	11.16	3.92 (sd)

Table 1. Summary of measurements of total welding fume (mg/m^3) continued.

Place	Circumstance	Type*	Mean (mg/m^3)^	Range (mg/m^3)#
Iran, 2012[73]	Construction – gas pipelines	MMAW-iron	21.52	9.40 (sd)
Germany, 2014[@74]	Manufacturing	FCAW + GMAW (2008) FCAW + GMAW (2011)	4.1 (GM) 0.5 (GM)	1.2-13.9 0.2-2.0
Sweden, 2014[@75]	Manufacturing	GMAW-MS	2.3	0.1-38.3
U.S., 2015[76]	Shipbuilding	FCAW MMAW	3.18 (GM) 0.75 (GM)	3.6 (gsd) 4.5 (gsd)

*: MS=mild steel; SS=stainless steel; BP=boiler plate; vent=ventilation
^: arithmetic mean unless otherwise specified; med=median; GM=geometric mean
#: sd=standard deviation; IQ=interquartile range; gsd=geometric standard deviation; n.d.=not detected
@: Respirable fraction of fume (all other measurements are of total fume)

The measurements were virtually all taken in the breathing zone of the worker, within the helmet. The data show widespread variation in levels of welding fume suggest that in many workplaces in other countries, exposure to welding fume is often above the relevant occupational exposure level. It is not known if that is also the case in Australian workplaces but there is good reason to consider it might be given the similarities in work practice compared to Australia in many of the countries in which the studies were based. There are likely to be several different influences on the fume levels across studies, including the workplace circumstances, the type of welding, the material being welded and the official occupational exposure levels of the relevant country at the time. So, there is some limitation to comparing across studies, but the results provide a good guide to the levels of fume and the fume constituents across a range of real-world exposure circumstances.

Table 2. Summary of measurements of selected metal constituents of welding fume (mg/m^3).

Place	Circumstance	Type*	Chromium (mg/m^3)^	Chromium (VI) (mg/m^3)^	Manganese (mg/m^3)^	Nickel (mg/m^3)^
Germany, 1990[77]	Shipbuilding	GMAW-SS MMAW-SS	0.010 med (<0.001-0.080) 0.004 med (<0.001-0.050)			0.100 (0.50-0.320) 0.072 (<0.50-0.260)
Denmark, 1990[53]	Construction	MMAW-MS GTAW-SS	0.003 (sd 0.002) 0.015 (sd 0.011)	0.002 (sd 0.001) 0.004 (sd 0.003)	0.132 (sd 0.102) 0.004 (sd 0.002)	
Netherlands, 1990[54]	Various	FCAW GMAW-SS GTAW-SS MMAW-SS	 0.310 (0.060-1.100) 0.320 (0.025-1.600)	 0.050 (0.0.10-0.280) <0.001 0.250 (0.014-1.500)		 0.100 (0.40-0.370) <0.001 0.057 (0.010-0.210)
Denmark, 1991[55]	Manufacturing	(GMAW+MMAW)-MS GTAW-SS	0.003 (sd 0.008) 0.011 (sd 0.011)	0.001 (sd 0.001) 0.003 (sd 0.002)		
New Zealand, 1991[24]	Various	GMAW-MS GTAW-SS	0.006 <0.007-0.012			 <0.006-0.010
Denmark, 1992[56]	Manufacturing	GMAW-SS GTAW-SS GTAW + MMAW	0.015 (sd 0.006) 0.028 (sd 0.060) 0.017 (sd 0.014)			0.012 (sd 0.009) 0.015 (sd 0.017) 0.012 (sd 0.013)
England, 1992[57]	Shipyard	MMAW-MS			0.140 (sd 0.162)	
Finland, 1992[58]	Shipyard	MMAW-MS			0.364 (0.080-0.690)	
Czechoslovakia, 1992[78]	Manufacturing	MMAW-SS	0.064 GM (0.007-0.161)			0.028 GM (0.003-0.070)
Poland, 1993[@59]	Various	MMAW-SS	0.005-0.991	0.005-0.842		

Table 2. Summary of measurements of selected metal constituents of welding fume (mg/m^3) continued.

Place	Circumstance	Type*	Chromium (mg/m^3)^	Chromium (VI) (mg/m^3)^	Manganese (mg/m^3)^	Nickel (mg/m^3)^
Norway, 1994[60]	Shipyard: - Ship-section - Platform - Welding shop	 MMAW-SS MMAW-SS MMAW-SS	 0.230 (0.008-1.000) 0.030 (0.005-0.087) 0.050 (<LOD-0.270)	 0.140 (0.004-640) 0.006 (<LOD-0.018) 0.012 (<LOD-0.084)	 0.041 (0.015-0.120)	 0.050 (0.003-0.150) 0.011 (0.002-0.041) 0.014 (0.006-0.039)
France, 1997[79]	Manufacturing	GMAW-MS MMAW-MS GMAW-SS GTAW-SS MMAW-SS	0.007 (0.001-0.018) 0.008 (0.001-0.020) 0.185 (0.013-1.200) 0.052 (0.001-0.308) 0.201 (0.016-1.328)	0.001 (0.001-0.001) 0.001 (0.001-0.001) 0.004 (0.001-0.065) 0.002 (0.001-0.016) 0.086 (0.001-0.649)		
U.S,, 2000[32]	Construction	GMAW, GTAW, MMAW	0.100 (0.002–0.558) 0.060 (0.000–0.450)	 0.010 (0.002–0.020)	0.200 (0.001–1.311) 0.070 (0.001–0.470)	0.060 (0.001–0.488) 0.050 (0.000–0.460)
U.S., 2001[62]	Manufacturing	FCAW-BP GMAW-SS GTAW-SS	0.013 (gsd 0.016) 0.090 (gsd 0.065) 0.003 (gsd 0.001)		0.556 (gsd 1.642) 0.111 (gsd 0.070) 0.003 (gsd 0.002)	0.012 (gsd 0.014) 0.035 (gsd 0.031) 0.002 (gsd 0.001)
Poland, 2002[63]	Manufacturing	GMAW-Al (total) GMAW-Al (resp)	0.003 (0.002-0.007)		0.014 (0.002-0.049) 0.008 (0.002-0.016)	
U.S., 2002[64]	Construction	MMAW-MS			0.0100 (? – 0.196)	
Germany, 2004[80]	Shipyard	FCAW-SS	0.200 (0.002-2.744)	0.011 (0-0.151)		0.050 (<0.002-0.417)
New Zealand, 2004[65]	Engineering	(GMAW + GTAW)-SS - Factory 1 - Factory 2 - Factory 3 - Factory 4	 0.002 0.001 0.001 0.002		 0.008 0.003 0.031 0.180	 0.002 0.038 0.001 0.001

Table 2. Summary of measurements of selected metal constituents of welding fume (mg/m^3) continued.

Place	Circumstance	Type*	Chromium (mg/m^3)^	Chromium (VI) (mg/m^3)^	Manganese (mg/m^3)^	Nickel (mg/m^3)^
Poland, 2004[66]	Industrial	FCAW	0.004-0.500		0.010-1.800	<0.004
Russia, 2006[81]	Manufacturing and shipyard	All-SS MMAW-SS FCAW-SS GMAW-SS	0.037 GM (0.003–0.976) 0.057 GM (0.005–0.976) 0.009 GM (0.003-0.018) 0.073 GM (0.007–0.387)		0.073 GM (0.003–3.930 0.126 GM (0.018–0.393) 0.012 GM (0.003–0.053) 0.153 GM (0.007–0.741)	0.021 GM (0.002–0.270) 0.034 GM (0.003–0.240) 0.007 GM (0.002–0.025) 0.028 GM (0.002–0.270)
U.S., 2007[82]	Construction	FCAW + MMAW			0.021 (0.010-0.038)	
U.S., 2009[68]	Boiler repair	MMAW-CS			0.120 (0.090-0.130)	
Korea, 2009[83]	Manufacturing	GMAW-MS			0.140 (0.002-0.254)	
Saudi Arabia, 2010[69]	Manufacturing	MMAW-MS - All - Factory 1 - Factory 2 - Factory 3 - Factory 4 - Factory 5 - Factory 1			 0.138 (0.010-0.477) 0.111 (0.080-0.142) 0.107 (0.062-0.184) 0.217 (0.026-0.477) 0.081 (0.010-0.129) 0.209 (0.019-0.279) 0.104 (0.050-0.187)	
U.S., 2011[27]	Manufacturing	GMAW-MS GTAW-MS MMAW-MS	0 (0-002) (0-0.002) 0.002 (0-0.002)		0.051 (0.015–0.150) (0.005–0.007) 0.032 (0.008–0.075)	0 (0.001) (0-0.002) 0 (0-0.003)

Table 2. Summary of measurements of selected metal constituents of welding fume (mg/m^3) continued.

Place	Circumstance	Type*	Chromium (mg/m^3)^	Chromium (VI) (mg/m^3)^	Manganese (mg/m^3)^	Nickel (mg/m^3)^
Germany, 2012[71]	Manufacturing	Inhalable-MS/SS - All - FCAW - GMAW - GTAW Respirable-MS/SS - All - FCAW - GMAW - GTAW			Median (IQ) 0.073 (0.010-0.340) 0.585 (0.180, 1.393) 0.180 (0.037, 0.360) 0.010 (0.005, 0.027) 0.062 (0.008, 0.320) 0.600 (0.270, 1.100) 0.140 (0.030, 0.320) 0.008 (0.004, 0.022)	
Iran, 2012[72]	Construction – gas pipelines	MMAW-iron	0.020 (sd 0.002)	0.002 (sd 0.001)		0.083 (sd 0.127)
Iran, 2012[73]	Construction – gas pipelines	MMAW-iron			0.304 (sd 0.256)	
Germany, 2014@[74]	Manufacturing	FCAW + GMAW (2008) FCAW + GMAW (2011)	0.187 (0.040-0.256) 0.006 (0.001-0.89)		0.399 (0.100-2.171) 0.007 (0-0.140)	0.076 (0.015-0.248) 0.003 (0.01-0.049)
Sweden, 2014@[75]	Manufacturing	GMAW-MS			0.17 (<0.01–2.13)	
U.S., 2015[84]	Construction – oil refinery	MMAW-MS: confined MMWA-MS: open			0.099 (gsd 0.003) 0..009 (gsd 0.004)	
U.S., 2017[85]	Manufacturing – heavy equipment	GMAW-MS - Factory 1 - Factory 2 - Factory 3 - Combined			 0.053 (gsd 0.003) 0.150 (gsd 0.002) 0.120 (gsd 0.002) 0.088 (gsd 0.003)	

*: MS=mild steel; SS=stainless steel; BP=boiler plate || ^: arithmetic mean (range) unless otherwise specified; med=median; GM=geometric mean; sd=standard deviation; IQ=interquartile range; gsd=geometric standard deviation || @: Respirable fraction of fume (all other measurements are of total fume)

Table 3. Summary of measurements of selected gaseous constituents of welding fume (ppm).

Place	Circumstance	Type	Ozone (ppm)^	NO_2 (ppm)^	NO (ppm)^	CO (ppm)^
Netherlands, 1990[54]	Various	FCAW-MS GMAW-MS GMAW-SS GTAW-MS+SS MMAW-MS+SS	0.5 <0.0025 >0.5 <0.0025 <0.0025			<=5 <=5 <=5 <=5 <=5
New Zealand, 1991[24]	Various	GMAW-MS GTAW-SS		<0.01-0.70 <0.3-21.2	<0.01-0.17 <0.04-13.8	1.2-1.8
England, 1992[57]	Shipyard	MMAW-MS		0.06 (sd 0.03)	0.25 (sd 0.27)	1.1 (sd 0.5)
U.S., 2001[62]	Manufacturing	FCAW-BP				10
Iran, 2011[86]	Manufacturing	All GMAW GTAW	0.30 (sd 0.19) 0.37 (sd 0.22) 0.21 (sd 0.12)	3.41 (sd 0.63) 3.29 (sd 0.60) 3.54 (sd 0.65)	0.52 (sd 3.00) 0.54 (sd 3.20) 0.41 (sd 2.70)	
U.S., 2011[27]	Manufacturing	GMAW-MS GTAW-MS MMAW-MS	0.012 (0-0.37) 0.0047 (<LOD-0.020)	0.038 (0.037-0.061) 0.064 (0.052-0.220)		
Iran, 2012[87]	Construction – gas pipelines	MMAW-iron	0.018 (0-0.0371)	0.397 (0.01-0.58)		1.477 (0.375-4.33)
Sweden, 2014[@75]	Manufacturing	GMAW-MS	0.040 (<0.0001-0.66)			

*: MS=mild steel; SS=stainless steel

^: arithmetic mean (range) unless otherwise specified; sd=standard deviation; LOD=level of detection

INFLUENCES ON FUME LEVELS

As mentioned, there are likely to be a number of factors that influence the level of welding fume, either total fume or the constituents of the fume. These factors are considered in detail in the remainder of this chapter. Some of the main factors influencing fume level are summarised in Table 4, which is based on the work of Hobson and co-workers, who reviewed information on welding fume levels published up to 2010[88]. It shows mean levels (and ranges) of total welding fume for different industry settings, welding type, base metal being welded, the degree of enclosure, the type of ventilation present, the location of the collection filter and the year in which the study was undertaken. Their study found that welding type and the degree of enclosure explained 76% of variation in the welding fume concentration.

WORKPLACE DESIGN

Other workers in the area where welding occurs are also at risk of being exposed to harmful levels of welding fume and welders may be exposed to fume generated by the welding of other workers. No studies were identified which directly addressed workplace design as a way of controlling such exposures, although this was alluded to in passing in several papers. Separating welding from other activities and the use of barriers of some form are both likely to be helpful, in addition to the use of ventilation, which is considered below.

WELDING TYPE

Different welding types have different potentials for generating welding fume. However, it has been noted that in many circumstances it may not be possible to change the type of welding used as it might be inherent to the reason the welding is done[40].

Table 4. Summary of measurements of total welding fume in various circumstances (ppm) (based on the work of Hobson and co-workers[88]).

	Arithmetic mean	Range of means	Range of individual measures
Industry			
Manufacturing	7.48	0.16-37.2	0.05-449.1
Shipyard	5.32	2.70-13.0	0.30-112.0
Construction	4.86	1.72-9.33	1.00-37.30
Welding type			
FCAW	15.23	6.31-24.15	1.17-55.46
GMAW	2.02	1.01-2.90	0.05-12.00
GTAW	0.72	0.16-1.10	0.06-4.10
MMAW	4.14	1.72-9.33	0.30-37.3
Base metal			
Mild steel	6.28	1.10-24.15	0.40-112.0
Stainless steel	5.12	0.16-37.20	0.05-449.1
Mild and stainless steel	4.58	3.00-5.80	0.10-37.30
Enclosure			
Confined	12.52	4.90-37.20	0.30-449.1
Enclosed	4.38	2.30-9.33	0.70-77.80
Open	3.85	0.16-24.15	0.03-74.40
Ventilation			
None	3.64	0.63-6.70	0.30-112.00
General	8.94	0.16-37.20	0.05-449.10
Local	3.30	1.99-6.31	0.50-55.46
Collection filter location			
Outside helmet	9.34	1.10-37.20	0.05-449.1
Inside helmet	1.73	0.63-3.38	0.05-449.1
Time period			
1980-1989	8.69	0.96-37.20	0.10-449.1
1990-1999	2.96	0.63-5.80	0.03-37.3
2000-2009	5.02	0.16-9.33	0.05-55.46

Flux-core arc welding tends to produce more fume than gas tungsten arc welding[62, 70, 71, 89]; gas metal arc welding[74, 90]; and manual metal arc welding[74, 76, 89, 91]. In contrast, studies of mild steel and stainless steel welding found the highest fume exposures arose from manual metal arc welding, with flux-core arc welding next highest and gas metal arc welding lowest[92, 93]. In a laboratory study, fume production and chromium (VI) and manganese levels in fume were found to be higher in manual metal arc welding compared to gas metal arc welding[94]. Other studies have found fume exposures were higher in gas metal arc welding and manual metal arc welding than in gas tungsten arc welding[27, 95]. Particle solubility can be expected to be a determinant of manganese absorption from fume and has been found to be higher in manual metal arc welding than gas metal arc welding[96]. The results from published workplace studies that provide comparison of fume level with different welding techniques are shown in Table 5 (and are briefly summarised in Table 4). This shows considerably higher exposure levels with flux cored arc welding compared to the other types, with gas tungsten arc welding generally having the lowest exposure levels.

Pulsed arc transfer during gas metal arc welding compared to conventional gas metal arc welding has been found to decrease welding fume in field conditions, primarily due to the lower temperatures possible while still achieving an effective weld[97].

Table 5. Summary of measurements of total welding fume by welding type (mg/m^3).

	Welding type			
Setting	**FCAW^**	**GMAW*^**	**GTAW^**	**MMAW^**
Construction[53]			1.3	4.7
Various[54] - Mild steel - Stainless steel	 4.0 (2.9-6.8) 	 4.6 (1.5-14.2) 5.9 (1.0-19.4)	 1.3 (0.7-3.3)	 4.6 (1.0-11.0) 11.3 (2.1-41)
Various[24]		2.56 (0.93-4.19 (MS)	0.63 (0.33-1.28)	
Manufacturing[56]		1.01	0.98	
Manufacturing[62]	8.97 (1.17-55.46)	1.61 (0.49-2.67)	0.16 (0.06-0.27) 0.79 (0.32-1.85)	
Manufacturing[63] - Total - Respirable		 6.0 (0.8-17.8) 2.6 (0.7-6.0)	 0.69 (0.25-1.36) 	
Manufacturing[27]		0.510 (0.140-1.700)	(0.046-0.077)	0.63 (0.15-2.1)
Manufacturing[70] - Inhalable - Respirable	 8.02 (IQ 2.83, 12.05) 7.11 (IQ 4.53, 10.10)	 3.65 (IQ 1.80, 5.69) 2.08 (IQ 1.20, 3.78)	 <0.58 (IQ <0.42, 0.93) <0.42 (IQ <0.36, <0.51)	 1.12 (IQ 0.52, 3.55) 0.49 (IQ <0.45, 1.85)
Manufacturing[71] - Total - Respirable	 6.24 (IQ 1.05, 12.40) 6.87 (IQ 3.36, 10.1)	 2.71 (IQ 0.74, 5.02) 1.64 (IQ n.d., 3.34)	 0.56 (IQ <LOD, 0.93) n.d. (n.d., 0.46)	
Shipbuilding[76]	3.18 (gsd 3.6)			0.75 (gsd 4.5)

*: MS=mild steel

^: arithmetic mean (range) unless otherwise specified; gsd=geometric standard deviation; LOD=level of detection; n.d.=not detected.

The type of shielding gas has also been found to be an important determinant of the rate of formation of welding fume, with increasing proportions of carbon dioxide and oxygen, when mixed with argon, resulting in increased fume formation[29]; much lower amounts of chromium (VI) produced with gas metal arc welding using inert gases than active gases as shielding; and carbon dioxide found to produce high levels of particles[98-102] and ultrafine particles[9] in gas metal arc welding. The inclusion of additives to the shielding gas has also been shown experimentally to significantly decrease the levels of chromium (VI), manganese and nickel in the fume, but the safety in the workplace and the effect on the weld quality of potential additives has not yet been established[103-106]. It is also clear that there are many influences on the amount of chromium (VI) produced and no single recommendation can appropriately cover all exposure situations[107].

General ventilation

General ventilation involves the use of extraction fans and other forms of equipment to move air in the workplace. Natural ventilation may also be important, especially in outdoor or very open workplaces. The aim is to move contaminated air away from the breathing zone of workers and dilute the amount of unwanted constituents in the air in the workplace. This contrasts with local exhaust ventilation (LEV), which involves the use of a hood and extraction fan to remove the fume from the area of the welding[29] and thus decrease the amount of fume reaching the breathing zone of the worker; and on-tool extraction, in which the fume is extracted at the site it is produced[108].

General ventilation can be important in open workshop areas to decrease the concentration of welding fume by diluting it with fresh air and moving contaminated air from the work area[61, 76]. However, it is rarely sufficient as a replacement for LEV or on-tool extraction[109].

Push-pull ventilation systems were examined in welding operations in a laboratory stetting and were found to effectively reduce fume concentration in the breathing zone of the worker as long as flow rates were at least 0.3 m/s[110]. Fans and downdraft tables can also be effective. A combination of approaches has been found to be effective in theoretical and simulated studies of large industrial halls that had a lot of welding occurring[106].

The extent to which the welding activity is enclosed is an important determinant of exposure[29, 111], presumably because of the influences on air flow and effectiveness of various ventilation control mechanisms. It is also important that general ventilation systems are properly designed and maintained, otherwise there is a high likelihood that the systems will provide insufficient protection, exposing the welder and their colleagues to considerable risk[112].

LOCAL EXHAUST VENTILATION

As mentioned, LEV involves the use of ventilation equipment near the welding area with the aim of removing the fume from the area of the welding, thereby decreasing the amount of fume reaching the breathing zone of the worker. It can be an effective and efficient control mechanism[6]. The type used depends on a range of factors but most particularly on whether the welding is being conducted in a fixed workplace, in which case fixed ventilation can be used, or a mobile workplace, in which case the LEV needs to be portable.

Many studies have been conducted examining the effectiveness or otherwise of local exhaust ventilation. These studies have covered a range of industries, but most particularly the construction and manufacturing industries. Local exhaust ventilation has been found to be an effective approach to decrease the level of contaminants in the breathing zone of workers. This is the case for total fume and for individual constituents in the fume such as manganese and chromium (VI). These studies are summarised below.

One study found a 60% reduction through the use of LEV (some units not having any filter and some units using a high efficiency particulate air filter) compared to what was described as natural ventilation (outdoor air or outdoor air coming inside through open windows or doors)[32], although re-analysis of the same data suggested the percentage reduction varied considerably between different occupations and thus different welding circumstances[30]. The same authors, who conducted a re-analysis of data from several other studies, concluded that "*…there is evidence that local exhaust ventilation can control the exposures to manganese and total fume but that mechanical ventilation may not.*"[30]. Another study involving re-analysis of data from several sources found LEV ("*…bell-shaped hood or nozzle…was attached to the end of a flexible … hose to capture fume. The entry of the hood was placed [50–75 mm] above the weld.*") reduced the median concentration of chromium (VI) by 68%, but in a controlled setting rather than a field setting[113].

Another study comparing the use of LEV ("*a portable vacuum and a small bell-shaped hood connected by a flexible … hose*") to no exposure control during welding in construction found a 10% reduction in total particulate and a 53% reduction in manganese concentration in field studies and larger reductions (60% and 75%, respectively) in laboratory studies[67].

The authors of a major review of the use of local exhaust ventilation use in welding in the construction industry concluded "*…LEV can produce substantial reductions in welding fume exposures relative to natural or general ventilation when used correctly…*" (they cite average decreases of at least 40 to 50%); and that "*… substantial reductions in total fume, Mn, and CrVI are possible with LEV, and in some cases result in exposures below current [occupational exposure limits].*" They also highlighted the importance of work practice, airflow rate, the environment surrounding the worker, and ergonomic and design factors associated with LEV in influencing the effectiveness of LEV during welding[31].

A number of individual studies provide some insight into the advantages and challenges of using various forms of LEV (and on-tool fume extraction systems). The type of LEV has been found to be important, with a direct comparison study of manual metal arc welding in a large tank outdoors and inside finding that a small, portable unit positioned close to the welding area ("*portable fan unit on a support stand with a flexible arm*") was more effective than an 'elephant trunk' extractor ("*a mobile, wheeled fume extractor unit with a 2 metre flexible arm*"). The study also found that in some circumstances external air currents could be the dominant determinant of fume levels, having much more of an influence on fume levels than LEV[114]. An Indian study found both 'portable' and 'mobile' locally made LEV devices were effective in decreasing manganese exposures by between 63% to 88% compared to background conditions during electric arc welding[115]. A small study of a locally made LEV with the hood positioned close to the welding torch head reported a capture efficiency of 77%[116]. Studies have found that when welding in confined spaces, dilution ventilation was insufficient and required the use of LEV or respiratory PPE to achieve suitable exposure levels[117, 118]. An LEV device with a hood that completely covered the welding pool was found to be a very efficient way to capture fume (and shield exposure to ultraviolet radiation) on a hand-held welding gun. However, it had the disadvantage of completely obscuring the welding area, requiring use of a specially designed camera with a laser to provide images for the welder[119].

The use of area cooling fans may interfere with the effectiveness of on-tool fume extraction systems because of changes to the air flow pattern. Perhaps even more concerning, inefficient use of LEV can increase fume concentration levels in air[70]. Finally, in a recent review of exposure standards relevant to welding in the United Kingdom, it was noted that LEV is much less effective in outdoor conditions and that respiratory protection might well be necessary in such circumstances regardless of the use of LEV[26].

ON-TORCH EXTRACTION

On-torch extraction can provide an effective means of decreasing exposure to fume for several reasons. The extraction is integrated with the welding gun; the extraction moves with the weld; the extraction is very close to the source at all times; and it doesn't rely on the welder to move LEV to appropriately capture fume because the capture mechanism moves as the welding gun moves and remains close to the source of the weld at all times[108, 120].

On-torch extraction devices do have drawbacks, however. They can be heavy and so interfere with the welder's ability to perform the required work tasks; they may interfere with the weld quality or be perceived to interfere with the weld quality; and they may obscure the view of the welder[108, 120]. Integrated exhaust systems have been found to be effective in decreasing levels of manganese and other contaminants in air, but this is dependent on them being used properly, which has been found to be a challenge because of the weight of the equipment and a perception among operators that the equipment adversely affects the quality of the weld[3, 62, 121]. One study found the particular concern of welders was that the fume extraction was also removing some of the shielding gas, which in turn resulted in problems with the welds. To attempt to minimise this, the welders would move the collar of the fume extraction device, attempting to decrease the air flow. Not surprisingly, this decreased the effectiveness of the ventilation system[62].

The information from published workplace studies which provide measures of the influence of ventilation on welding fume levels are shown in Table 6.

Table 6. Summary of measurements of welding fume by ventilation (mg/m³).

Study*	Without ventilation	With ventilation	Welding type
Manufacturing[@74]	4.1 (1.2-13.9)	0.30 (0.20-0.50) *LEV and on-torch extraction*	FCAW and GMAW
Construction[#67]	5.6 (range 2.7-11.6)	4.6 (range 3.2-5.4) *LEV*	MMAW
Manufacturing[%61]	About 0.008 at 20 metres	About 0.004 at ground level *Displacement mechanical*	FCAW
Construction[^32]	5.39	LEV 1.99; mechanical 1.72	GMAW, GTAW, MMAW
Manufacturing[&62]	15.83 (1.17-55.46)	5.77 (1.33-21.36) *On-torch*	FCAW

*: All measures are of total welding fume except as noted

@: respirable particles; GM (range). Comparison of respirable values before and after a detailed intervention: "*The ventilation system was subjected to extensive improvements. Multiple junctions facilitated the connection of a larger set of local exhaust ventilation (LEV) devices. Welding torches with integrated fume extraction were installed. The type was chosen after practical testing by the workers. Additionally, mobile ventilation units were provided. Floor cleaning was converted from a dry to wet method to reduce the airborne dust load. Helmets with purified air supply were offered to the welders working at the container construction who had to work in confined spaces. These helmets were connected to compressed air system of the factory hall by a tube. The supplied air was purified in a special filter system upstream. Formerly, welders in the container section had used maintenance-free particulate respirators (dust mask).*"

#: total fume; GM (range). "*Breathing zone samples collected outside the welding hood; compared LEV with no LEV - ""a portable vacuum and a small bell-shaped hood connected by a flexible 2 inch (50.8 mm) diameter hose.*"

%: Chromium (VI). "*The air distribution system of the hall was based on displacement. Two air handling units controlled by a central system delivered inlet air through seven low impulse diffusers into the hall. ..... The air was exhausted with two roof fans.*"

^: (Susi, 2000) – total fume; arithmetic mean

&: total fume; median (range); *welding gun extraction system*

COATINGS, FLUXES AND ELECTRODES

The constituents and structure of coatings, cores and fluxes have been found to be important determinants of the degree of welding fume generated, and probably more important than the base metal[29].

In terms of the flux, cored wires have been found to produce much less fume than normal flux in many[99, 122] but not all[123] studies.

Electrode type clearly influences fume formation. In terms of the main content of the electrode, using nickel-copper electrodes instead of stainless steel electrodes was found to decrease the level of chromium (VI) in welding fume by two orders of magnitude in gas tungsten arc welding and manual metal arc welding[124]. Other studies have also found electrode type (and the base metal being welded) was an important determinant, along with the welding type, of the level of nickel and/or chromium in the welding fume[13, 91, 103, 125].

A study of the influence of the type of material used to cover the electrode examined fume composition and physical and chemical behaviour using rutile, acid, basic and rutile-cellulose coverings on standard industrial electrodes during arc welding. The study recommended using acid-covered electrodes because the fume particles associated with these electrodes were found to sediment out of the fume more quickly[126, 127]. Nano-coating (nano-alumina or nano-titania) with stainless steel manual metal arc welding electrodes has been found to lead to a decrease in the formation of chromium (VI) (40% and 76% respectively). Paradoxically, increase in total fume formation rate was found to decrease chromium (VI) levels due to decreased production of ozone which in turn decreased the amount of chromium that was converted to chromium (VI)[128]. There was higher fume formation with cellulose-coated electrodes compared to rutile-coated electrodes in a small controlled study of manual metal arc welding in the shipbuilding industry[129].

The role of shielding gases in influencing the levels of ozone in fume has not been fully elucidated for all welding types. It appears that helium leads to lower ozone concentration than does argon if the anode is solid, but might increase ozone concentrations at high helium concentrations with molten anodes[130], and ozone has been found to persist for up to 10 minutes after welding ceases[131]. In another study, fume formation in gas tungsten arc welding was lowest with 100% argon shielding and highest with a shielding mixture of 82% argon and 18% CO_2[132].

The material being welded can have surface coatings that can be heated during the welding process, producing harmful constituents that become incorporated into the welding fume. These coatings may include chromium, lead, zinc and tin[133].

WORK PRACTICE AND TRAINING

Work practice is an important determinant of both the amount of fume generated and the degree of exposure of the welder to that fume. A recent review found that "*the convective dispersion of the fume away from the weld and the interaction of the welder with the fume plume were also important.*" … "*When the welders head is positioned directly above the arc source, exposure levels are higher than when welding vertically with the head to the side... Interaction between the welder and the source is likely to be one of the key [modifying] factors influencing welder exposure…*"[29].

For example, work practice was found to be a determinant of fume level in welders in confined spaces in ship-building[118], and a recent study found that nearly all welders had worked with their head in the welding plume for at least some of the time, prompting the authors to propose that welders undergo training on proper work practice to reduce their exposure[89].

The electrical current and voltage are important determinants of the amount of fume, and in one recent review they were stated to be *"… probably the single greatest influencing factors on the generation of welding fumes for FCAW … and GMAW…."*[29]. Arc current (and voltage) appears to be an important determinant of particle concentration in all forms of welding, with higher current (and higher voltages) leading to higher particle concentration in fume[9, 28, 99, 101, 123, 129, 134-137]. An Iranian study of aspects of the welding process recommended that workers use the lowest voltage and current, and the highest travel speed (defined as "*the speed of the welding electrode on the metal base*"), that can be used while still maintaining the quality of the weld[28]. Arc current was found to be the main determinant of particle concentration in plasma cutting in one study, with higher current producing higher fume concentration. However, as lower current levels may prove insufficient to cut metal, the authors recommended that workers balance these two aspects and use as low a current as possible that would still cut metal[136].

In contrast to the Iranian study just mentioned, welding speed (independent of voltage) was found to have little influence on the rate of fume formation in manual metal arc welding[129] and in gas metal arc welding[134].

Improving work practice through training, and using jigs to help optimally position material to decrease fume rising into the breathing zone of the worker, can be useful additions to approaches designed to minimise worker exposure to welding fume. Appropriate work practice includes not having the head in the welding fume and positioning the work to maximise the effectiveness of the ventilation[109]. A simulation study of stud welding found that fume exposure could be moderately decreased by modifying the posture of the welder[138].

RESPIRATORY PROTECTION

When welding fume cannot be appropriately controlled by the range of control measures already mentioned, which is not uncommon in the workplace, some form of personal respiratory protection will be necessary. There are several different forms of protection available, including disposable masks, half-face respirators with replaceable filters, air-purifying respirators and supplied air respirators. Standard welding helmets have been found to considerably reduce worker exposure to welding fume, but the level of reduction varies with the welding process and the position of the welder[95]. Often the most appropriate and increasingly commonly used form is the purified-air powered respirator, which moves with the worker, is easier to wear and provides fresh and often cool air to the breathing zone of the worker, making it easier to wear for longer periods[109, 120].

Limited quantitative data on the benefits of any of the respirators exist, particularly purified-air powered respirators or powered air supply respirators. A German study compared respirable and environmental levels of various fume components in welders to values three years earlier in the same workplace. In between, several changes had been made to try to improve exposures. These included improvements in the use of LEV, introduction of on-torch fume extractors and the use of purified air supply helmets when working in confined spaces (inside metal containers being welded), whereas previously welders had worn dust masks. There were considerable improvements in measured parameters, but the multiple changes made it difficult to ascribe the improvements to any single control measure. Comparison of environmental measures to respirable measures (which were taken inside the helmets) showed the purified-air supply helmets were extremely effective in decreasing the concentrations of all relevant constituents measured in the respirable air. Particulates decreased from about 0.5 mg/m^3 to 0.3 mg/m^3, manganese decreased from 21 mcg/m^3 to

2.3 mcg/m^3, chromium decreased from about 7.5 mcg/m^3 to 2.3 mcg/m^3 and nickel decreased from 2.7 mcg/m^3 to 1.1 mcg/m^3. For manganese, this meant values that were above the proposed German occupational exposure level were decreased to values only about 12% of that proposed level. The authors noted a much more modest increase in biological exposure measures of the metals. They suggested this may have been due to welders spending time without their helmets on, during which time they would have been exposed to the higher concentrations of fume at the environmental level, emphasising the importance of having appropriate general ventilation, LEV and housekeeping (keeping the work area clean) rather than relying purely on respirators to obtain suitably low exposures for the workers[74].

Earlier studies study by a similar group found that the level of contaminants in air inside the purified-air powered respirators were nearly always below the level of detection, but the authors noted that purified-air powered respirators might not always be practical to use inside confined spaces (which presumably is where they could be of highest benefit)[70, 71].

Guidance for selecting appropriate respiratory protection during welding is available[120, 139]. A comparison study of four types of respiratory protection - surgical facemask, cotton-fabric facemask, activated-carbon facemask and N95 respirator – found that all removed at least 98% of particulate matter and at least 84% of reactive oxygen species in the particulate phase. However, none effectively removed reactive oxygen species in the gaseous phase. The best-performed in this regard was the N95 respirator, which still only removed about 21% of reactive oxygen species[140].

SUMMARY

Welding fume exposures in workplaces appear to commonly be above the relevant occupational exposure level. It is not known if that is also the case in Australian workplaces but there is good reason to consider it might be given the similarities in work practice compared to Australia in many of the countries in which the studies were based. The main factors that influence the amount, nature and composition of welding fume appear to be the welding type, composition of the flux, type of consumable electrode, type of material being welded, the presence and type of coating on the material being welded and the strength of the current used. The amount of fume that reaches the breathing zone of the worker is influenced by all these aspects, as well as by aspects such as the use of ventilation, the air flow, the space in which the welding is being done (confined, indoors or outdoors), the position of the welder's head in relation to the fume plume and the use of helmet or respirator.

A range of control measures are suitable to control exposures and many should apply in the vast majority of welding circumstances. The evidence suggests that in many circumstances LEV or on-tool extraction will be sufficient to produce acceptable levels of total fume and individual contaminants. However, there are also many circumstances where this will not be the case. In such circumstances, it is important that welders use properly fitted respirators. In terms of being effective and practical, the most appropriate seems to be purified-air powered respirators. Powered air supply respirators are also very effective but are less practical and not usually able to be used in outdoor settings. When used properly, both these approaches should control exposures of welders to well below the exposure standard and should minimise the risk of welders developing lung cancer as a result of exposure to welding fume. A summary of the information on percentage decrease in welding fume, from studies where direct comparison of fume levels was provided, is shown in Table 7.

Table 7. Percentage decrease in welding fume by welding type and ventilation type

Control measure	Decrease in fume
Welding type (compared to Flux cored arc welding (FCAW))	
Gas metal arc welding (GMAW)	71%
Gas tungsten arc welding (GTAW)	94%
Manual metal arc welding (MMAW)	85%
Ventilation (compared to no ventilation)	
Mechanical	68%
Local exhaust ventilation	10% - 63%
Welding gun extraction	64%
Purified air powered respirator	93%

An important finding of a number of the studies was that it is not just welders who risk being exposed to concerning levels of fume and the associated increased risk of developing lung cancer. Persons working in the same general area where welding is undertaken may also be exposed, necessitating the use of effective control measures relevant to all workers, such as separating workers from the welding area by distance and by physical barriers (such as welding curtains) and having effective general ventilation and fume extraction in the workplace.

5 RESULTS – ULTRAVIOLET RADIATION

INTRODUCTION

This chapter provides a consideration of the published literature relevant to the control of exposure to ultraviolet radiation from welding.

WELDING OVERVIEW

As mentioned, ultraviolet radiation from welding has been classified by IARC as a known human carcinogen (Group 1), with melanoma of the eye being the outcome of concern. The increased risk appears to be independent of welding type[25, 33]. This ultraviolet radiation can also cause keratoconjunctivitis and skin erythema[141], but the focus of the current consideration is controlling the risk of welding-associated ultraviolet radiation that can result in melanoma of the eye. Influences on the amount of ultraviolet radiation generated appear to be the type of welding and the work practice used. The amount of ultraviolet radiation reaching the eye of a worker depends on these and also on the use of appropriate shielding and PPE.

WORKPLACE DESIGN

Other workers in the area where welding occurs are also at risk of receiving significant exposures to ultraviolet radiation. Apart from ensuring such workers wear appropriate eye protection (as discussed below), it is helpful to design the workplace to be able to use a curtain or other partition so that the welding area can be shielded from other workers[19, 41, 141, 142].

WELDING TYPE

Several studies have compared the intensity of ultraviolet radiation associated with different types of welding. These have found largely consistent results. A recent study considered the amount of ultraviolet radiation emitted during gas tungsten arc welding, manual metal arc welding and gas metal arc welding of cast iron. The study found that the highest levels were with gas metal arc welding, which was greater than manual metal arc welding, which was greater than gas tungsten arc welding[141]. Other studies have found much higher levels of ultraviolet radiation with gas metal arc welding compared to gas tungsten arc welding[143-145];

and in gas tungsten arc welding of aluminium compared to gas tungsten arc welding of other material and to manual metal arc welding[146].

In terms of shielding gas, increased levels of ultraviolet radiation have been found with metal inert gas welding and tungsten inert gas welding of magnesium alloys when the shielding gas was helium[143]; and with gas metal arc welding of mild steel when the shielding gas was 80% argon and 20% carbon dioxide, compared with 100% carbon dioxide[145].

Higher ultraviolet levels with gas metal arc welding of mild steel have been found with pulsed currents[145] and during spray transfer[145].

Maximum allowable exposure times for the radiation levels before permissible levels are exceeded have been found to be very short. The recent study of gas tungsten arc welding, manual metal arc welding and gas metal arc welding of cast iron estimated periods of only between 1.4 and 67 seconds per day[141]. Other laboratory and field studies have identified similarly low exposure times before the maximum permissible daily level is reached[143-146], and a theoretical study modelled the ultraviolet radiation exposures with gas tungsten arc welding and estimated the permissible exposure duration for a 'typical' gas tungsten arc welder was 5.9 seconds at 0.5 metres and just under 10 minutes at five metres[147].

On-torch modifications

No studies were identified which considered the effectiveness or otherwise of on-tool modification to control the amount of ultraviolet radiation resulting from the welding process.

Coatings, fluxes and electrodes

The level of ultraviolet radiation appears to be influence by the flux used – with iron resulting in higher levels than either nickel or chromium[141].

Higher levels of ultraviolet radiation were found with electrodes containing oxides compared with pure tungsten electrodes in gas tungsten arc welding of aluminium[144].

Work practice and training

More ultraviolet radiation has been found to be produced at higher current levels, regardless of the type of welding[141]; in gas metal arc welding and gas tungsten arc welding of magnesium alloys[143]; in gas metal arc welding of mild steel[145, 148]; and in gas tungsten arc welding of aluminium[144]. Levels of radiation have also been found to increase with arc length[147].

There were no studies identified that directly addressed the role of training in controlling exposures to ultraviolet radiation during welding.

Helmets, goggles and visors

As noted, welders can receive more ultraviolet radiation than the acceptable daily limit in only a few seconds to a minute in total, depending on the welding type and circumstances. Therefore, it is very important that welders wear a face shield before they start the arc. In the past this may have been difficult because the shield may have been too dark to properly see the welding area prior to the arc starting. However, auto-darkening shields in welding helmets are now available. Some form of welding helmet should be used at all times immediately before and during welding, with the auto-darkening helmets making this easier and thus making their use more likely[141].

Other workers in the area where welding occurs are also at risk of receiving significant exposures to ultraviolet radiation. So, it is important they also use some appropriate form of eye protection[20, 41, 141].

A detailed letter to the editor of one journal summarised work which showed that even when wearing an apparently properly functioning welding helmet, welders could still receive significant ultraviolet radiation exposure to their head by the radiation entering from the back, sides and top of the helmet, depending on the design. More importantly, as welders spend much of their day not welding but in the vicinity of others who are welding, they can easily receive excessive exposure to ultraviolet radiation to the eyes. Wearing goggles all the time while at work might overcome this problem, but welders have reported these are uncomfortable. The author proposed that auto-darkening helmets might be a suitable solution to avoid the need to raise the helmet so often[149].

Summary

The main factors that appear to influence the levels of ultraviolet radiation associated with welding appear to be the workplace design, the type of welding, the shielding gas and the type of flux and electrode. The main determinant of the amount of ocular ultraviolet radiation exposure to the welder, apart from the length of time welding, is the use of an appropriate face shield. The evidence strongly supports using auto-darkening visors. The short period (sometimes less than a minute) of unprotected exposure allowable before limits are exceeded strongly suggest that welders, and others in the workplace where welding is occurring, should wear suitable goggles at all times. If this does not occur, it is difficult for welders to adequately protect themselves from ultraviolet radiation exposure arising from the welding of other workers, even if they diligently wear appropriate eye protection when they are welding. As with the findings in regards to fume, perhaps even more so, there is a need to protect other persons working in the vicinity of welders from exposure to ultraviolet radiation. Separating workers from the welding area by distance and by physical barriers (such as welding curtains) and ensuring other workers wear appropriate goggles to protect from ultraviolet radiation, is very important to decrease the risk of ocular melanoma (and other disorders related to ultraviolet radiation exposure).

6 DISCUSSION

INTRODUCTION

This chapter consider aspects of the methodology used in the preparation of the report, the coverage and quality of the included studies, and the implications that has for the presented results.

IDENTIFICATION OF RELEVANT LITERATURE

It is difficult to know if all relevant publications were identified but it seems likely that the vast majority were. This assessment is based on the detailed search strategy, which was designed to be sensitive in order not exclude relevant papers; the use of relevant databases, which should have contained the vast majority of relevant articles; the secondary searches based on apparently relevant studies cited in the articles that were identified in the original search; and the fact that the vast majority of potentially relevant articles cited in the review papers were identified in the original search.

The main searches were limited to articles published from 2000 onwards but were supplemented by articles published back to 1990. Some of the review articles did refer to papers published before 2000, but the papers published since appeared to cover similar areas and there is an advantage to focussing on recent technology wherever possible as this is more relevant to current practice. The exclusion of earlier papers is not thought to have resulted in the omission of important relevant results.

The review of possibly relevant publications by title and abstract was potentially limited by only being undertaken by one person. However, this review was done carefully, and decisions revised on the few occasions a provisionally excluded publication was cited in a review article and found to be relevant. There were some difficulties deciding whether to include studies that were not focussed on the topic of the search, but which might have had peripheral information of relevance. In such instances, the full text was consulted before a final decision was made. Also, for some areas where there was a lot of published information which all came to a similar conclusion, not all the relevant articles were necessarily cited. The original plan for this project had been to rely heavily on review articles, but the limited number and scope of these meant that many individual studies were also included.

Another challenge was what to do with review articles which appeared to provide a good overview of an area but cited little or no published evidence, instead providing a general overview of a relevant area. In some instances, these were included to support or explain a specific aspect, but many were not included or were just mentioned as a group in passing.

Of the 150 papers that were identified by the search and through other means, the vast majority were cited. For those that were not cited in the main text, their findings were considered to have been suitably covered in other publications that were cited[2, 4, 5, 7, 8, 10, 12, 17-23, 150-154] or the full publication could not be found publication and there was insufficient information in the abstract to properly assess the study and its findings[11, 14, 16].

ASSESSMENT OF STUDY QUALITY

The studies were all critically appraised, but this proved a challenge for one or more of several reasons. Some were based on only a few subjects; some were extremely technical, providing much more detail than was required or appropriate for the current review; and some provided only limited information on their methods. Emphasis was also given to workplace-based studies rather than laboratory simulation studies.

The assessment of study quality necessarily has a considerable subjective component and necessarily contains a qualitative component. The assessments were only undertaken by one person, which means they contain a subjective element that will reflect the skills and biases of the assessor. Nevertheless, the assessment was undertaken by a very experienced epidemiologist with particular strength in critical appraisal of epidemiological studies and the assessment was able to be undertaken consistently. Therefore, it is reasonable to consider the critical appraisal of epidemiological aspects of studies to have been undertaken thoroughly. Many of the papers were lab-based occupational hygiene papers rather than being epidemiological in focus. The reviewer has specialist qualifications in occupational medicine, including covering occupational hygiene topics, but is not a practising occupational hygienist. To that extent it is possible some of the subtle methodological aspects of the included studies might not have been fully appreciated. However, the nature of the studies and their reporting, and the cross-checking where available with comments on the papers in review articles, suggests this did not impact importantly on the assessments.

Strengths and limitations of included studies in terms of the project aims

There was a considerable amount of information about the usefulness or otherwise of local exhaust ventilation. There was also considerable information about the influence of different welding types on fume formation. However, it was noted that there may not be much opportunity to change welding type in a particular work situation, which would limit the usefulness of information comparing exposures with different welding types.

As noted by some of the reviewers, many of the relevant studies had small sample sizes, were undertaken in laboratory conditions rather than in real workplaces, and for some aspects of the welding process and associated control measures there is very limited information[31]. There were surprisingly few studies providing objective evidence of the effectiveness of respirators, although at face value such effectiveness would be expected and the few studies to provide useful information did find that purified and supplied air respirators were extremely effective.

The main shortcoming of identified papers in terms of the project aims is that there was little information on the expected exposure when using each identified control method. Where such information was available or implied and considered to be useful, it has been included. There was also virtually no information for Australian workplaces.

Relevance to the Australian context

Very few of the studies were based in Australia; seven in total and only two examined Australian workplaces – one published in 1983[155] and the other a PhD thesis from 1998[156]. In descending order, the first authors of the identified studies were based in the following countries: the United States (55) the United Kingdom (12), Germany (12), Japan (8), Australia (7), Iran (6), Portugal (6), Poland (5), India (4), Canada (3), Denmark (3), France (3), Russia (3), Taiwan (3), Turkey (3), China (2), Finland (2), South Korea (2), Sweden (2), Czechoslovakia (1), Netherlands (1), New Zealand (1), Norway (1), Palestine (1), Saudi Arabia (1), Serbia (1), (for two publications, the home country of the first author was not known). The lack of studies in Australia is unlikely to be an important drawback for this project because the welding practice and available controls in Australia are likely to be similar to those in the developed countries where most of the studies occurred – the United States, the United Kingdom, the countries of Western Europe and Japan. Nevertheless, the lack of available objective quantitative data of welding fume exposure levels in Australian workplaces is concerning. Presumably this lack of data could be easily rectified by undertaking measurements and/or by obtaining data already collected by industry.

Industry was not directly relevant to the topic of the majority of the papers (that is, the focus was relevant to the welding rather than the context of the welding); where industry was mentioned the most common industries were manufacturing, ship-building and construction, all of which are relevant to Australia, although the first and third much more so than the second.

RECOMMENDATIONS

It is recommended that WorkSafe Victoria:

- consider how it might obtain information on current welding fume exposure levels in Victorian workplaces, as this would usefully supplement the information currently available from the published literature
- strongly encourage the use of purified-air powered respirators by welders in most situations during welding
- strongly encourage the use of goggles by all welders, and other workers in the vicinity, when welding is being undertaken
- strongly encourage the use of auto-darkening visors and for these to be worn before the welding arc is started
- make the information in this report available to workers and employers in workplaces where welding takes place.

7. CONCLUSIONS

This report has met the main aim of the study – to provide a detailed review of the epidemiological and occupational hygiene literature regarding exposure to fume and ultraviolet light arising from welding and associated control methods. There was a reasonable amount of information about welding fume exposure in general, but almost no published information about this for Australia. There was also a limited amount of information about how absolute exposure levels in real-world settings change with different control measures, but what information is available has been summarised and provides useful guidance.

There are many factors that influence the amount, nature and composition of welding fume and a range of suitable control measures, but little quantitative information about how each of these individually decrease exposure to below the exposure standard. In virtually all instances of welding, some form of ventilation and/or respiratory protection is likely to be required. Powered purified-air or air supply respirators should decrease exposure to well below occupational standards. Similarly, there are many factors that influence the amount of ultraviolet radiation associated with welding. The high intensity of this exposure means that goggles should probably be worn at all times and auto-darkening face shields used immediately before and during welding. Both welders and other persons in the welding work area are at risk from the associated exposures and the design and supply of appropriate control measures must take both into account.

The findings of the report should assist WorkSafe Victoria in providing appropriate up-to-date advice on control measures used to decrease the risk of cancer arising as a result of exposures associated with welding. Recommendations to support this endeavour are provided.

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APPENDIX 1 –SEARCH METHODOLOGY

This section shows the search approach used in the Medline and SCOPUS searches and the results of the searches.

SEARCHES FOR WELDING FUME

SCOPUS

TITLE-ABS-KEY (weld* AND fume AND (expos* OR hazard*) AND (prevent* OR control* OR reduc* OR protect* OR shield* OR safety)) AND PUBYEAR > 1999

MEDLINE

Search Strategy:

----

1 Welding/ or weld*.mp. (6301)
2 Inhalation Exposure/ or Occupational Exposure/ or Welding/ or fume.mp. or Air Pollutants, Occupational/ (72330)
3 1 and 2 (2962)
4 Humans/ or expos*.mp. (19087240)
5 Chemical Hazard Release/ or hazard*.mp. (292284)
6 4 and 5 (239387)
7 prevent*.mp. (2355615)
8 control*.mp. (5349562)
9 reduc*.mp. (3494345)
10 protect*.mp. (844065)
11 shield*.mp. (28511)
12 Chemical Safety/ or Safety/ or Equipment Safety/ or safety.mp. (558009)
13 7 or 8 or 9 or 10 or 11 or 12 (8911146)
14 3 and 6 and 13 (158)
15 limit 14 to yr="2000 -Current" (112)
16 from 15 keep 1-112 (112)

****

SEARCHES FOR ULTRAVIOLET RADIATION FROM WELDING

SCOPUS

TITLE-ABS-KEY (weld* AND (uv OR u-v OR ultraviolet OR ultra-violet OR flash) AND (expos* OR hazard*) AND (prevent* OR control* OR reduc* OR protect* OR shield* OR safety)) AND PUBYEAR > 1999

MEDLINE

Search Strategy:

----

1 Welding/ or weld*.mp. (6301)
2 Humans/ or expos*.mp. (19087240)
3 Chemical Hazard Release/ or hazard*.mp. (292284)
4 2 and 3 (239387)
5 prevent*.mp. (2355615)
6 control*.mp. (5349562)
7 reduc*.mp. (3494345)
8 protect*.mp. (844065)
9 shield*.mp. (28511)
10 Chemical Safety/ or Safety/ or Equipment Safety/ or safety.mp. (558009)
11 5 or 6 or 7 or 8 or 9 or 10 (8911146)
12 Ultraviolet Rays/ or ultraviolet.mp. (177645)
13 Ultraviolet Rays/ or UV.mp. (199812)
14 Ultraviolet Rays/ or ultra-violet.mp. (78928)
15 U-V.mp. (693)
16 12 or 13 or 14 or 15 (272516)
17 1 and 16 (193)
18 17 and 4 and 11 (30)
19 limit 18 to yr="2000 -Current" (21)