Welding and Thermal Cutting Fume – Potential for Occupational Health Issues

Position Paper

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AUSTRALIAN INSTITUTE OF OCCUPATIONAL HYGIENISTS INC (AIOH)

The Australian Institute of Occupational Hygienists Inc (AIOH) is the association that represents professional occupational hygienists in Australia. Occupational hygiene is the science and art of anticipation, recognition, evaluation, and control of hazards in the workplace and the environment. Occupational hygienists specialise in the assessment and control of:

- Chemical hazards (including dusts such as silica, carcinogens such as arsenic, fibrous dusts such as asbestos, gases such as chlorine, irritants such as ammonia and organic vapours such as petroleum hydrocarbons);
- Physical hazards (heat and cold, noise, vibration, ionising radiation, lasers, microwave radiation, radiofrequency radiation, ultra-violet light, visible light); and
- Biological hazards (bacteria, endotoxins, fungi, viruses, zoonoses).

Therefore, the AIOH has a keen interest in the potential for workplace exposures to welding and thermal cutting fume, as its members are the professionals most likely to be asked to identify associated hazards and assess any exposure risks.

The Institute was formed in 1979 and incorporated in 1988. An elected governing Council, comprising the President, President Elect, Secretary, Treasurer and three Councillors, manages the affairs of the Institute. The AIOH is a member of the International Occupational Hygiene Association (IOHA).

The overall objective of the Institute is to help ensure that workplace health hazards are eliminated or controlled. It seeks to achieve this by:

- Promoting the profession of occupational hygiene in industry, government and the general community.
- Improving the practice of occupational hygiene and the knowledge, competence and standing of its practitioners.
- Providing a forum for the exchange of occupational hygiene information and ideas.
- Promoting the application of occupational hygiene principles to improve and maintain a safe and healthy working environment for all.
- Representing the profession nationally and internationally.

More information is available at our website – http://www.aioh.org.au.

WORKPLACE EXPOSURE ASSESSMENT COMMITTEE MISSION STATEMENT

The AIOH established the Workplace Exposure Assessment Committee to provide expert guidance and comment to the exposure standards setting process at a State and National level and internationally where appropriate, through development of AIOH Position Papers, AIOH guidance publications or comment on relevant Standards, Regulations and Codes of Practice. The Committee's remit is to confirm that the exposure standards numbers, and Standards and Codes of Practice, are changed for valid occupational hygiene and scientific reasons.

STATEMENT OF POSITION REGARDING AIOH POSITION PAPERS

The AIOH is not a standard setting body. Through its Position Papers, the AIOH seeks to provide relevant information on substances of interest where there is uncertainty about existing Australian exposure standards. This is done primarily through a review of the existing published, peer-reviewed scientific literature but may include anecdotal evidence based on the practical experience of certified AIOH members. The Position Papers attempt to recommend a health-based guidance exposure value that can be measured; that is, it is technically feasible to assess workplace exposures against the derived exposure value. It does not consider economic or engineering feasibility. As far as reasonably possible, the AIOH formulates a recommendation on the level of exposure that the typical worker can experience without significant risk of adverse health effects.

Any recommended guidance exposure value should not be viewed as a fine line between safe and unsafe exposures. They also do not represent quantitative estimates of risk at different exposure levels or by different routes of exposure. Any recommended exposure value should be used as a guideline by professionals trained in the practice of occupational hygiene to assist in the control of health hazards.

CONSULTATION WITH AIOH MEMBERS

AIOH activities are managed through committees drawn from hygienists nationally. This Position Paper has been prepared by the Workplace Exposure Assessment Committee, with comments sought from AIOH members generally and active consultation with particular members selected for their known interest and/or expertise in this area. Various AIOH members were contributors in the development of this Position Paper.

Key contributors included: Ian Firth, Zachary du Preez, Linda Apthorpe, Alan Rogers, Ross Di Corleto and Robert Golec.

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LIST OF ABBREVIATIONS AND ACRONYMS

AIOH	Australian Institute of Occupational Hygienists
ACGIH	American Conference of Governmental Industrial Hygienists
COH®	Certified Occupational Hygienist
COPD	Chronic obstructive pulmonary disease
FCAW	Flux-cored arc welding
GMAW	Gas metal arc welding
GTAW	Gas tungsten arc welding
HSE	Health & Safety Executive, UK
IARC	International Agency for Research on Cancer
IIW	International Institute of Welding
IOM	Institute of Occupational Medicine
ISO	International Organization for Standardization
LOD	Limit of Detection
MAG	Metal active gas
MIG	Metal inert gas
MMAW	Manual metal arc welding
mg/m^3	milligrams (10^{-3} grams) per cubic metre
NATA	National Association of Testing Authorities
NOS / NOC	Not Otherwise Specified / Classified
NSW	New South Wales
OEL	Occupational Exposure Limit
PAPR	Powered air-purifying respirator
PAW	Plasma arc welding
SDS	Safety data sheet
SMAW	Shielded metal arc welding
STEL	Short-term exposure limit
SWA	Safe Work Australia
TIG	Tungsten-inert gas
TLV®	Threshold limit value®
TWA	Time Weighted Average
WES	Workplace Exposure Standard

DEFINITIONS

- Hazard: Means potential to cause harm.
- Risk: Means probability of harm actually occurring.
- Fume: Vapourised materials (e.g. metals) that are generally <0.05 µm in size and condense together. Welding and other thermal processes produce emissions which contain fumes and various gases. Note that when the welding industry talk about fume, they also include reference to the gases formed in the welding or allied process as well as remnant shielding gas. In this paper, the focus is on welding emissions as fume particulate.
- Limit of detection (LOD): The lowest concentration of a substance that can be feasibly determined to be statistically different (e.g. 3 times the standard deviation) from a sample that contains none of the substance (i.e. a blank sample).
- Respirable dust fraction: Contains particles smaller than 10 microns, with a mass median diameter of 4 microns. It is fine enough to be invisible to the naked eye and can be breathed deeply into the lungs.
- Inhalable dust fraction: Contains particles smaller than 100 microns and approximates to the fraction of airborne material that enters the nose and mouth during breathing.

AIOH POSITION ON WELDING AND THERMAL CUTTING FUME - POTENTIAL FOR OCCUPATIONAL HEALTH ISSUES

Key messages

- Welding and thermal cutting fume consists of very fine particles of metal oxides, silicates and fluorides depending on the composition of the metal being welded, the wire or electrode and any coatings.
- Welding and thermal cutting fume exposures are common in Australian workplaces.
- Welding and thermal cutting fume is a known human carcinogen and hazardous to the respiratory system. It may also cause kidney cancer.
- Safe Work Australia (SWA) currently has a welding fume WES of 5 mg/m^3 (measured as inhalable fraction) and proposed that this WES be discontinued, instead relying on the WES values for the individual hazardous contaminants in the fume.
- AIOH believe that exposures to welding and thermal cutting fume should be as low as reasonably practicable and recommend using a trigger value of 1 mg/m^3 for inhalable welding and thermal cutting fume, coupled with compliance with WES values for the individual elemental hazardous contaminants in the fume, utilised to implement controls.
- Health monitoring should be a part of the health management program.
- AIOH recommends stakeholders also use existing industry-specific guidance / best practice approaches with a strong focus on using processes and controls that reduce welding and thermal cutting fume, supplemented with appropriate training of workers to use welding and thermal cutting procedures to minimise exposure to fumes.

Summary

This Position Paper was compiled to provide guidance on the assessment, evaluation, and control of occupational exposure to welding and thermal cutting fume, with emphasis on use of a trigger value for fume which is Not Otherwise Specified / Classified (NOS / NOC).

Welding and thermal cutting fumes are produced as by-products of welding and thermal cutting processes. These fumes produce acute, chronic, and carcinogenic exposure risks and are heavily dependent on the welding process, materials/consumables used which produce various constituents in the fumes. These constituents may include, but are not limited to, aluminium, cadmium, hexavalent chromium, manganese, iron oxide, vanadium, zinc, and copper as well as solder pyrolysis products (rosins). In addition, gases including carbon monoxide, phosphine, phosgene, ozone, and nitrogen dioxide may be present.

Critical effects of exposure can include irritation of the upper respiratory tract (nose and throat), tightness in the chest, asphyxiation, asthma, metal fume fever, lung damage, bronchitis, cancer, pneumonia, and emphysema. Welding and thermal cutting fumes are classified as known human carcinogens (*Group 1*), upgraded from possibly carcinogenic to humans (*Group 2B*) in 1989 (IARC, 2018).

As part of their review of Australian workplace exposure standard (WES) values for airborne contaminants, SWA (SWA, 2020a) recommended no health-based time-weighted (TWA) WES for generic welding fume (NOC), instead relying on the respective WESs of the individual constituents in the fumes. The intention was that the individual WES values would be utilised to determine worker exposure and to establish when controls are required to be implemented or improved. Following industry consultation, SWA has maintained the current generic welding fume TWA-WES value of 5 mg/m^3, measured as inhalable fraction.

The AIOH believe that exposures to welding and thermal cutting fume should be maintained as low as reasonably practicable. There is existing industry-specific guidance / best practice approaches, which should be used. This Position Paper proposes that the current TWA-WES should be lowered to 1 mg/m^3 (as inhalable fraction), to be used as a trigger value to implement fume controls. The WES values for the individual constituents in the fumes must also be complied with.

The AIOH have several recommendations which are noted above and provided in more detail in the body of this document.

1. Background

The welding and thermal cutting of metals and alloys are well established processes where the associated health and safety hazards and their controls are well understood, if not always fully implemented. Welders are potentially exposed to metal fume and gases, ultraviolet radiation, noise, electric shock, burns and other hazards. Publications by Weld Australia (2020), Safe Work Australia (SWA, 2020b) and the NSW Department of Primary Industries (NSW DPI, 2003) provide details of the health and safety hazards of welding and thermal cutting and appropriate controls. This Position Paper focusses on the airborne contaminant hazards, principally the volatilised fume.

The recent re-classification of all welding fume as a known human carcinogen (*Class 1* Carcinogen) (IARC, 2018) has focused more attention on the control of airborne welding fume in the workplace.

Safe Work Australia (SWA, 2020a) recommended to remove the single health-based time-weighted average (TWA) workplace exposure standard (WES) for welding fume (NOC). They had suggested the withdrawal of the current TWA-WES of 5 mg/m^3, as part of their review of WESs for airborne contaminants. Instead, they recommended that the respective WESs of the individual constituents in the fumes be used to determine worker exposure. This is consistent with the recommendation from the American Conference of Governmental Industrial Hygienists (ACGIH®). However, following industry consultation SWA has decided to maintain the current TWA-WES value of 5 mg/m^3 pending further research.

It is essential that the individual WESs for welding and thermal cutting fume constituents (e.g. chromium VI, manganese, etc) are both health-based using realistic toxicological data, and measurable.

2. The different welding and thermal cutting processes

Welding is the process of joining metals through coalescence, by high heat or pressure or both (SWA, 2020b; American Welding Society, 2010). Approximately 80 different types of welding and allied processes for commercial use have been identified. However, the main types of welding include:

- Manual metal arc welding (MMA or MMAW), also known as shielded metal arc welding (SMAW) in the USA, flux shielded arc welding or stick welding
- Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) welding or metal active gas (MAG) welding, depending on the shielding gas used. MAG welding is an ISO/European term used for GMAW welding where the shield gas is active, usually an argon-based mix containing CO_2 and/or small addition of oxygen. It is colloquially (and incorrectly) referred to as "MIG" in Australia by many welders. MIG is GMAW welding with an inert shielding gas such as argon (Bruce Cannon, Weld Australia, pers com)
- Tungsten-inert gas (TIG) or gas tungsten arc welding (GTAW)
- Flux-cored arc welding (FCAW), including self-shielded, and gas shielded variants
- Friction welding
- Spot (resistance) welding, and
- Plasma arc welding (PAW).

Brazing and 'silver' soldering is also included.

Cutting and gouging methods include gas (oxy fuel) cutting, air-carbon arc gouging[1], oxygen lance, laser cutting, spark erosion and plasma. Plasma and oxy-fuel are the two most common thermal cutting processes.

3. What are welding and thermal cutting fumes?

Particulates generated during welding and thermal cutting are very small. In general, they have a diameter of less than 1 µm (in most cases < 0.1 µm; termed ultrafine particles), therefore they are respirable and called "welding fume". Besides individual particles, chains and agglomerates are also formed by coagulation (Spiegel-Ciobanu *et al*, 2020) when the fume is generated. While all welding and thermal cutting processes generate fume, the plume may not be visible to the welder, or with some processes, the observer (Weld Australia, 2021).

Welding and thermal cutting processes generate a variety of hazardous substances that can be absorbed by the human body (GMBl, 2020; Spiegel-Ciobanu *et al*, 2020). The composition of the substances being welded or cut, including coating and/or surface contaminants (e.g. greases, oils etc), the type of welding (e.g. filler metal & flux) and the way they are conducted can all play a role in the types and composition of airborne volatiles produced. Much of the materials in the welding fume come from the consumable electrode (Weld Australia, 2021).

Particulates are produced only in the immediate vicinity of the heat source. They are largely confined to the plume of heated gases which rises from the weld zone (Weld Australia, 2021), but can accumulate in poorly ventilated areas. While fumes derived from metals or their compounds mostly occur as oxides, the chemical properties of welding fumes can be quite complex (Table 1).

[1] Air-carbon arc gouging produces extremely high levels of fume and noise, as well as carbon monoxide (David Hamilton, pers com).

Table 1: Chemical properties of welding fume for some different metals (Weld Australia, 2021)

Metal Type	Fume May Contain	But May Also Occasionally Contain
Mild steel	iron, carbon, manganese, silicon[2] & aluminium	nickel, chromium, molybdenum, niobium, vanadium & boron
Stainless steels	iron, chromium & nickel	molybdenum, manganese, titanium & other elements
Aluminium	aluminium, silicon, iron, copper, manganese, chromium, zinc & titanium	• gallium, vanadium and/or boron in wrought alloys; & • tin and/or lead in cast alloys
Copper, bronze & brass alloys	copper, zinc, nickel, aluminium, tin, lead, silicon & iron	manganese, tellurium, sulphur, chromium, cadmium, beryllium, silver & cobalt

4. How do we measure it?

The measurement of fume typically requires occupational hygiene skills to sample the air in the beathing zone of the welder over several hours, with laboratory analysis of the fume particles collected. The Australian Standard 3853.1 (2006) '*Health and safety in welding and allied processes – Sampling of airborne particles and gases in the operator's breathing zone – Sampling of airborne particles*' describes the determination of personal exposure to welding fume and other airborne contaminants generated by welding related operations. Whilst the particle size range can be less than 1 µm, sampling airborne fumes generated from welding or thermal cutting processes requires the collection of the inhalable fraction of the aerosol as per AS 3640 (2009). This is followed by laboratory analysis of those constituents in the captured particulate deemed to be hazardous by an exposure risk assessment process.

The exposure risk assessment process for identifying hazardous constituents should apply the information in Table 1 and Attachment 2 of this document, in addition to information obtained from the Safety Data Sheet (SDS) for the metal type and for any coatings on surfaces being welded or cut, welding rods or other consumables used. The analysis of the mass of fume and the hazardous constituents shall be conducted by a NATA laboratory specifically accredited for the analysis and the results reported on NATA endorsed test certificates (refer to Section 10 for further specifics).

Air monitoring is employed to help confirm that the control measures in use are working correctly or to provide information to assess health risk. Also, health risk relative to guidance values relating to the need for controls and health monitoring should be determined by a Certified Occupational Hygienist (COH®).

The assessment of the potential for adverse health effects due to welding fume (NOC) and its various components (Attachment 1) should be performed by comparing personal exposures in the workplace to an 8-hour TWA-WES, as provided by Safe Work Australia (SWA). In addition, the investigation will also need to consider other factors that can influence exposure on the day, such as the production rate setting the amount of welding work needed, location of the task (e.g. in a designated bay, building or outside environments), presence of any ventilation (e.g. local extraction ventilation), and other ambient particulate exposures or dusty tasks conducted adjacent to the worker.

According to Breathe Freely Australia, *Monitoring Exposure to Welding Fume*, it is wise to conduct air monitoring when:

- Welding coated material, e.g. galvanised steel
- Using metals which have low exposure limits, such as nickel and chromium
- Fume is observed in the air coming away from the welding process[3]
- Fume is observed which is not being captured by the existing extraction
- There are concerns about the performance of the existing control measures, or
- You want to gather information which will help specify further control measures.

Note that Work Health and Safety Regulations state that air monitoring must be undertaken where there is uncertainty of potential exposures to welders.

When conducting personal air sampling of welding fume, it is preferable to have the sample head inside the welding helmet[4] to better determine operator exposures, although outside of any worn respirator. The sampling can be conducted with a conventional IOM inhalable particulate sampler head, but in most circumstances, it is cumbersome for the welding operator. Measured exposures for

[2] Note: this silicon is not crystalline silica or quartz. It is amorphous silica.

[3] Note that where there is no visible plume it does not necessarily mean that there is no hazard, therefore workers must be adequately protected (Section 8).

[4] Note that sampling inside of powered air-purifying respirators (PAPRs) is not recommended due to problems with sampler efficiencies. Lehnert *et al* (2012) noted though that measurements of welding particles are often below the LOD inside PAPRs.

welders can be confusing, as they may be taken inside or outside the welder's helmet. In the latter case, the measured levels will be higher but not actually represent the true exposure.

SKC provide a '[Face Level Sampling Headset]' (225-6201 Mini-Sampler), specifically designed for sampling within the breathing zone behind protective face shields. The headset-mounted mini sampler is said to be user friendly, easy to adjust individually, does not disturb the welder during sampling and allows sampling inside the personal protective equipment. The headset mounting arrangement improves personal sampling as it maintains the sampler close to the nose/mouth during the whole sampling period. However, practical experience suggests use of the headset and mini sampler is not necessarily straight forward.[5]

A study by Lidén and Surakka (2009) shows that the developed headset-mounted mini sampler is suitable for assessing exposure to manganese in welding aerosol. It meets BS EN ISO 10882-1:2011 - *Health Safety in Welding and Allied Processes: Sampling of Airborne Particles*.

It is important to remember that a full-shift personal sample will include the contribution of general workplace dust in addition to the emissions generated by the welding or thermal cutting process. The source and composition of the other workplace dust should also be understood. Furthermore, exposure measurements for individual welders can be highly variable due to the range of welding tasks and types, in conjunction with other factors within the work environment.

To determine efficacy of controls, representative welding duties need to be measured, with close observation. That is, task-based sampling should be undertaken, noting the welding conditions and controls. For this type of monitoring, the use of a real-time aerosol monitor is recommended. While such measurements may not be accurate, real-time monitoring rapidly demonstrates differences in exposures and can help the welders to appreciate how they can influence exposures during their welding/thermal cutting tasks.

5. Hazards associated with welding fumes

It is well documented that volatilised fumes and gases generated during the welding and thermal cutting processes can have adverse health effects on workers when inhaled.

Critical effects of exposure to welding fumes can include irritation of the upper respiratory tract (nose and throat), tightness in the chest, asphyxiation, asthma, metal fume fever, lung damage, bronchitis, cancer, pneumonia, and emphysema (SWA, 2020a & b). A detailed list of health effects of several of the individual particulate constituents of welding fume is presented in Attachment 1.[6] The International Institute of Welding (IIW) publication 'Hazardous Substances in Welding and Allied Processes' (Spiegel-Ciobanu *et al*, 2020) compiles the current knowledge on practically all hazardous substances in welding, soldering, brazing, and other allied processes that are relevant from a health and safety aspect. It provides information on process-dependent emission data and general information on health hazards and possible health effects of particles, gases, and their possible constituents.

In May 2017 the International Agency for Research on Cancer (IARC, 2018) reclassified welding fume from Group 2B "possibly carcinogenic to humans" to Group 1 "carcinogenic to humans".[7] The reclassification came following sufficient evidence that welding fumes cause lung cancer in humans, based primarily on the available epidemiological literature. These studies did not show that the cancer risk differed between mild steel and stainless-steel welding but were related to the total welding aerosol (i.e. fume). There was also a positive association observed with cancer of the kidney, although not all findings were statistically significant, most studies had only a few exposed cases, and there was little evidence of an exposure-effect relationship.

In the past, there has been particular concern about the potential cancer risks from welding stainless steel because of possible exposure to hexavalent chromium (Cr VI) and nickel, both known lung carcinogens, and tighter levels of control have often been advocated in these circumstances.

Welding fume exposure (median $PM_{2.5}$ concentration of 1.66 mg/m^3) was found to induce acute systemic inflammation in welders (Kim *et al*, 2005). In addition, chronic exposure to welding fume is associated with a decrease in pulmonary function and welders have an increased risk of chronic obstructive pulmonary disease (COPD), asthma and chronic bronchitis (Koh *et al*, 2015; IARC, 2018; Spiegel-Ciobanu *et al*, 2020).

Exposure to fine particles (respirable and nanoparticles) present in welding fume may also be associated with cardiovascular disease. IARC (2018) note that cardiac arrhythmias, myocardial ischemia, and atherosclerosis have been reported and epidemiological studies of male welders showed increased risk of cardiovascular disease, including hypertension. Taj *et al* (2021) found that exposure to welding fumes at low-to-moderate levels was associated with increased blood pressure.

[5] For example, when fitting the device to the welder, comfort, and ability for the welder to conduct their welding tasks still needs to be considered. Other considerations with the sampler include potential for cross-threading of the retaining ring and sampling body and its potential for the assembled head to become loose; use of a laboratory that is NATA accredited for analysis of the specific filters required to be used in the mini-sampler; and using a sample pump that is able to handle the recommended flow rate and back pressure produced as the sample collects on the filter (Kerry McDougall, pers comm).

[6] Note that this attachment only mentions particulate constituents. There may also be gases present, including carbon monoxide, phosphine, phosgene, ozone, and nitrogen dioxide.

[7] IARC incorrectly refer to thermal cutting fume as welding fume. In their discussion on thermal welding processes such as flame (oxy-acetylene) welding, it is acknowledged by the international welding fraternity that they should be referring to thermal cutting, as copious fume is produced in thermal cutting, but flame welding produces minimal (if any) fume. Note too that thermal cutting includes plasma cutting which produces fume similar to arc welding (Bruce Cannon, Weld Australia, pers com).

There is also consistent evidence that welders die more often of pneumonia, especially lobar pneumonia, are hospitalised more often for lobar and pneumococcal pneumonia, and more often develop invasive pneumococcal disease (Palmer & Cosgrove, 2013).

6. Potential for exposure

The nature and severity of risks will depend on various factors, including the (SWA, 2020b):

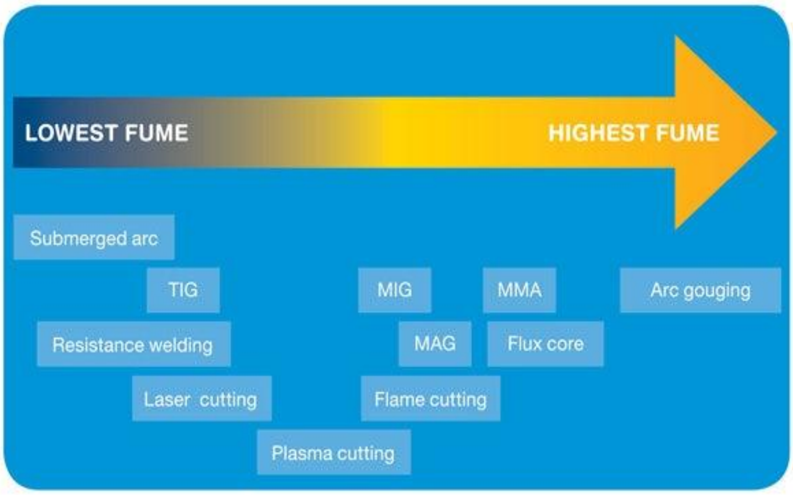
- The type of welding process being used, including electrodes
- Properties of the materials being welded
- Surface coating of the items being welded (for example whether they contain lead or other toxic materials)
- Condition of the welding equipment
- Conditions under which welding is carried out (e.g. working in confined spaces), and
- Skills, competence, and experience of the welder.

Lehnert *et al* (2012) carried out personal sampling of respirable and inhalable particles in the breathing zone of 241 welders. Median mass concentrations were 2.5 mg/m^3 for inhalable and 1.3 mg/m^3 for respirable particles when excluding 26 users of powered air-purifying respirators (PAPRs). The concentrations of respirable fume from personal measurements ranged from measurements less than the limit of detection (<LOD) up to 21.5 mg/m^3. Mass concentrations were highest when gas-shielded flux-cored arc welding (FCAW) was applied (median of inhalable particles: 11.6 mg/m^3). Measurements of particles were frequently below the LOD, especially inside PAPRs or during TIG welding. Concentrations were mainly predicted by the welding process and were significantly higher when local exhaust ventilation (LEV) was inefficiently used or when welding was performed in confined spaces.

Kendzia *et al* (2019) estimated inhalable and respirable welding fume exposure concentrations from the German database MEGA (compiled between 1983 & 2016). They found that the inhalable concentrations were approximately twice the respirable concentrations, with medians of 3 mg/m^3 (inter-quartile range: 1.2 - 7.0 mg/m^3) and 1.5 mg/m^3 (inter-quartile range: < LOD - 3.8 mg/m^3), respectively. The adjusted geometric means of FCAW, MIG and MAG welding, MMA welding and torch cutting ranged from 0.9 to 2.2 mg/m^3 for respirable welding fumes and from 2.3 to 4.7 mg/m^3 for inhalable fumes. In both particle-size fractions, geometric means were between 0.1 and 0.9 mg/m^3 when performing TIG, autogeneous[8], resistance, laser, and plasma welding or spraying.

The different types of welding / thermal cutting evolve different levels of fume. Level of evolved fumes, from highest to lowest, is said to be as follows (adapted from WorkSafe NZ, 2016 & Cancer Council):

- Arc air gouging
- Flux core (FCAW)[9]
- Manual metal arc welding (MMAW)
- Metal active gas (MAG)
- Flame cutting
- MIG
- Plasma cutting
- TIG
- Laser cutting
- Resistance and friction welding
- Submerged arc



More detail on evolved fume levels due to welding process, consumable and parent material composition is provided in Attachment 2.

In a survey of airborne metal exposures to welders, metalworkers, and bystanders in small fabrication shops using FCAW only, Insley *et al* (2019) found that of the 21 individual metals analysed for, only 8 were frequently detected. Exceedance fractions were less than 5% for all metals, except for manganese and iron oxide. Typical operations in the fabrication shops included metal cutting, bending, shaping, riveting, welding, grinding, buffing, chipping, machining, milling, turning, fastening, and engraving. The total particulate geometric mean

[8] Autogenous welding is a form of fusion welding without the addition of filler material. For example, autogenous Gas Tungsten Arc Welding (GTAW) or Tungsten inert gas (TIG) welding uses a non-consumable electrode to melt the parent material without the use of a filler rod.

[9] There are two main variants of this process – self shielded, which generates copious fume to protect the weld pool, and gas-shielded. Both are high productivity processes hence can generate much fume, but self-shielded is the worst (Bruce Cannon, Weld Australia, pers com).

concentration collected by area sampling near the welding processes was 0.24 mg/m^3. However, due to work environment factors such as fume dispersion, number of welders within the space and general ventilation, fume may also be an issue for bystanders.

Bémer *et al* (2010) characterised the ultrafine aerosol emitted by thermal spraying of metals (zinc, zinc/aluminium & aluminium) using flame and electric arc processes. They found that ultrafine particle (80 - 95% of number distribution <100 nm) emission rates produced by the electric arc process are very high, the largest values being recorded during spraying of pure aluminium. Brand *et al* (2013) found that welding processes with high mass emission rates (MMAW, MAG welding, MIG welding, MIG brazing, and laser welding) show mainly agglomerated particles with diameters above 100 nm and only few particles in the size range below 50 nm (10 to 15%). Welding processes with low mass emission rates (TIG welding and resistance spot welding) emit predominantly ultrafine particles with diameters well below 100 nm, which can be more toxic. They suggested that this finding can be explained by considerably faster agglomeration processes in welding processes with high mass emission rates. Such high particle emissions require careful consideration and possible rethinking of currently implemented protection measures (Section 8).

7. Risk of health effects

There is a very large cohort of workers who are potentially regularly exposed to welding fume and welding fume exposure contributes significantly to work-related burden of disease and injury (IARC, 2018).

The toxicity of fumes will vary with the type and quantity of material volatilised. The WES of a hazardous substance is indicative of its toxicity, but not definitive. Depending on the components and size of the fume generated, the particles may be absorbed into the bloodstream via the upper respiratory tract, or travel to the lower gas-exchange regions of the lungs.

Attachment 1 provides a list of hazardous welding / thermal cutting airborne contaminants and their WESs, as well as target health effects. In non-ventilated laboratory tests, most welding processes result in a breathing zone concentration greater than the current exposure standard (Weld Australia, 2021). However, when assessing full shift personal exposures where welding and thermal cutting only occur intermittently, it is possible that exposure concentrations will be less than the exposure standard, being diluted by other workplace exposures.

A meta-analysis of case-control and cohort studies on welding or exposure to welding fumes and risk of lung cancer supported the conclusion that exposure to welding fumes increases the risk of lung cancer, regardless of the type of steel welded, the welding method, and independent of exposure to asbestos or tobacco smoking (Honaryar *et al*, 2019). Welders had a meta-relative risk of lung cancer of between 1.17 and 1.87 when compared with those who have never welded or been exposed to welding fume. In addition, increased risks persist regardless of exposure time or occupational setting, and the risk increases with years of employment as a welder. However, this meta-analysis did not provide estimates for lung cancer risk by quantitative level of exposure to welding fumes. Similarly, IARC (2018) noted for the lung cancer studies used, that exposure effects were not consistent across studies and there was difficulty in quantifying exposure to welding fumes retrospectively, particularly for those relying on self-reporting by respondents.

Cherrie and Levi (2020) note that lung cancer risks were observable at very low exposure levels of inhalable welding fume; below 1 mg/m^3 and perhaps as low as 0.1 mg/m^3, averaged over a working lifetime. They suggest that due to the carcinogenicity of welding fume (and several of its constituents), a precautionary approach is needed to control welding fume exposures to the lowest levels practicable.

Harris (2019) noted that we are challenged by the fact that not all welding fume is the same. The IARC (2018) Group 1 carcinogenic potential of welding fume does not address the possible differences in carcinogenicity that may be exhibited by differing combinations of the metals and welding or thermal cutting processes involved. He discussed two possible approaches to deriving an exposure limit for welding fume: the additive formula model, and the aggregate undifferentiated fume model, preferring the latter. The total undifferentiated aggregate fume model was preferred as it involved: a single sample medium, and a single occupational exposure limit (OEL) for each common combination of consumable and process.

Note that just because a welding process has a low mass emission rate does not mean that it is necessarily less toxic than a high mass emission rate process (Section 6).

A consideration of the AIOH (2016) trigger values for Dust (NOS) of 5 mg/m^3 for the inhalable fraction and 1 mg/m^3 for the respirable fraction, may provide some guidance for a welding fume limit value. The following limitations however need to be considered regarding the Dust (NOS) trigger values:

- They are based on reducing the risk of COPD only, not other lung and cardiovascular diseases
- They relate to exposure to insoluble particulate whilst welding fume can be a mixture of soluble metal complexes and insoluble metal and non-metal particulate, all of which contribute to toxicity, and
- The value for respirable particulate does not account for a potentially high exposure to nanoparticles (exposure to which vary depending on the type of welding process). These do not contribute significantly to the mass of the respirable fume but are potentially associated with an increase in oxidative stress and lung inflammatory response due to their large surface area/volume ratio and composition.

Taj *et al* (2021) suggest that an OEL value of less than 2.5 mg/m^3 (as the respirable fraction) is needed to protect cardiovascular health of workers. Median respirable dust concentrations, adjusted for respiratory protection, of the welders in this six-year longitudinal study were 0.5 to 0.7 mg/m^3.

As noted by SWA (2020a) though, "Given the significant composition variability in welding fumes, a gravimetrically determined WES that can adequately protect workers cannot be determined."

8. Available controls

Controls should focus on prevention of exposure with priority given to the higher order controls in the hierarchy of controls. It is essential that the general ventilation of the workplace is adequate to prevent the accumulation of hazardous airborne contaminants from welding and thermal cutting processes. Where local extraction ventilation is used it must not negatively impact on the quality and integrity of the weld. Usually, a combination of control methods may be required to minimise the welder's exposure to fume.

It is also essential that workers who conduct welding and thermal cutting processes understand the associated health hazards and are trained in using the controls effectively. Using the hierarchy of controls in the order of their effectiveness, occupational exposure to welding fumes can be controlled by:

- Elimination of the need to weld or cut (e.g. use of pre-cast components or extruded shapes)
- Substitution with a safer (lower fume) alternative process or consumables
- Efficient containment and ventilation of processes (e.g. use of local exhaust ventilation) or fume capture using on-tool extraction (where feasible) with the aim to capture the fume close to the source of generation.
- Forced ventilation (e.g. via use of pedestal fans) may be utilised providing the fume is not directed at other workers). Fans may also provide some thermal comfort to workers
- Consideration of discharge locations not posing risk to neighbouring work parties who may not be utilising controls used by the welder themselves
- The provision of regular education and training in health effects caused by welding and how welders can protect themselves
- Consideration or assessment of the need to implement health monitoring
- Ready access and correct use of personal respiratory protective equipment (e.g. PAPR fitted with P2 filters, fit tested negative pressure respirators), selected, used and maintained as per AS/NZS 1715 (2009)
- Administrative controls, including inspection and maintenance of controls such that they are fit for purpose, and restricted access to areas where the welding or thermal processes are conducted, and
- A suitable location to store and clean used personal protective equipment.

Safe welding (and thermal cutting) practices are described in various government publications, such as the Safe Work Australia (SWA, 2020b) Code of Practice for 'Welding Processes' and the NSW Department of Primary Industries (NSW DPI, 2003) 'Guideline for Safe Cutting and Welding at Mines'.

Breathe Freely Australia also provides good resources for implementing controls for welding fume exposures. A key resource is the Weld Australia (2021) publication 'Fume Minimisation Guidelines: Welding, Cutting, Brazing & Soldering'. As detailed in this document, key control methods are:

- Where practicable, remove the welder from the source of the fume by mechanising or automating the welding process
- In conformance with Weld Australia's Fume minimisation guidelines, arrange the work piece so that the welder's head is not in the plume
- Do not expect a light cross-draught in the vicinity of the welder's face to reliably remove the fume from the welder's breathing zone. Whilst mechanically assisted ventilation (e.g. a fan) can be utilised, cross draughts sufficient to disperse fume may cause weld quality issues. Other fume management equipment such as fume extractors (e.g. fixed, downdraft or portable) may be required
- Utilise personal protective equipment such as respirators (e.g. P2) and air-fed helmets if alternative methods of fume control are not reasonably practicable, and
- A combination of fume control methods that includes the use of personal protective equipment (e.g. PAPR, air-fed helmets, etc) may be necessary to minimise the welder's exposure to weld fume.

Keane *et al* (2014) found that although no single process is the best for minimising fume emissions and costs while satisfying the weld requirements, there are several processes that can minimise emissions. Fume emission rates per gram of electrode consumed were highest for MMAW (~13mg fume per g electrode) and lowest for GMAW processes such as pulsed spray (~1.5mg/g) and Cold Metal Transfer™ (CMT ~1mg/g).[10] Manganese emission rates per gram of electrode consumed ranged from 0.45 mg/g (MMAW) to 0.08mg/g (CMT). Nickel emission rates were generally low and ranged from ~0.09 (GMAW short circuit) to 0.004mg/g (CMT). Iron emission rates ranged from 3.7 (spray-mode GMAW) to 0.49 mg/g (CMT). More detail on fume emission rates and controls are provided in the German publication 'Technical Rule for Hazardous Substances (TRGS) 528: Welding work' (GMBl, 2020).

9. Current exposure standards

Only some of the Western world has set a TWA exposure limit for welding fume (NOS / NOC), of between 1 and 5 mg/m^3, either as the inhalable or the respirable fraction, as per the Gestis database for international limit values, with most (79%) set at 5 mg/m^3 (inhalable fraction). The adoption of a 5 mg/m^3 limit value in most jurisdictions was based on the old ACGIH® TLV® at the time, which was established to protect workers against a significantly increased risk of metal fume fever. The current Australian WES for welding fume (NOS as inhalable fraction) is a TWA value of 5 mg/m^3.

[10] CMT is a proprietary version of waveform-controlled welding, in this case waveform-controlled dip mode. SST is another variant and there are other proprietary variations on this (Bruce Cannon, Weld Australia, pers com).

In Germany, the exposure limit and regulation for general dust or non-specified welding fume (where no other specific exposure limit exists for that substance) is 1.25 mg/m³ as the respirable fraction (GMBl, 2020), based on the TRGS 900 Exposure Limits. This exposure limit is based on preventing chronic, particle-related inflammatory processes in the lungs (BAuA, 2014). In the Netherlands the health-based exposure limit for welding fume is 1 mg/m³, applicable to 'inert' welding fume particles not containing toxic metals such as chromium and nickel (DECOS, 1993). It was based on total particulate collected, where a safety factor was applied to the no-observed-adverse-effect level of 5 to 6 mg/m³ (determined for effects on the respiratory system) and 3.2 mg/m³ (determined for effects on the male reproductive system).

Spiegel-Ciobanu *et al* (2020) suggest that "for all processes with unalloyed/low alloy material (parent and filler materials), where the portions of chromium, nickel, cobalt, manganese, copper, barium, fluoride are individually below 5% by weight and where no mutagenic, carcinogenic, fibrogenic, toxic or sensitising substances are contained in the welding fume, it is in most cases sufficient to determine the concentration of the welding fume/respirable fraction for comparison with the relevant limit value specified for workplace exposure". Otherwise, the limit value of the relevant key compound(s) will be the determining factor.

It should be noted that this mass-based approach does not give information on the risks ofexposure to nanoparticles generated during the welding process.

10. AIOH recommendation

The AIOH believe that exposures to welding and thermal cutting fume should be kept as low as reasonably practicable and consider that a TWA-WES for welding and thermal cutting fume (NOS / NOC) would be useful as a guidance value to trigger appropriate controls. We propose the use of 1 mg/m³ (as inhalable fraction), noting that other hazardous substances in the welding fume should be identified through a risk assessment process by applying the information in Table 1 and Attachment 2 of this document, in addition to information obtained from the SDS for the metal type and for any coatings on surfaces being welded or cut, welding rods or other consumables used. Where there is the potential for exposure to hazardous individual fume constituents, then the fume on the sample filter should be analysed for the appropriate metallic elements and the results assessed against their respective current WES values such as those listed in Attachment 1. This recommendation may also be applied to fumes from thermal cutting and metal smelting processes.

The AIOH recommend the use of a NATA laboratory specifically accredited to conduct welding fume analyses and accredited for the analysis of the various hazardous constituents, and the results reported on NATA endorsed test certificates. Also, health risk relative to guidance values relating to the need for controls and health monitoring should be determined by a Certified Occupational Hygienist (COH®).

The AIOH believe it is important that health monitoring is also utilised, particularly for Schedule 14 hazardous chemicals (e.g. cadmium, chromium & lead). The SWA 'Health monitoring guides' should be followed.

Given the complex aspects of welding and thermal cutting fume toxicity and exposure assessment, rather than depending only on an airborne regulatory exposure limit (i.e. a WES), the AIOH believe it would be in the best interest of all stakeholders to also use existing industry-specific guidance / best practice approaches. Such approaches already exist, including the fume minimisation guidelines described by Weld Australia (2021). Training of workers in the correct and safe conduct of welding and thermal cutting to minimise exposures is of paramount importance.

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Attachment 1: Workplace Exposure Standards for Welding / Thermal Cutting Fume (Particulate) Contaminants

Substance	Current WES	Proposed WES	Health Effect
Welding fume	TWA = 5 mg/m^3	None	Known human carcinogen; chronic lung effects (Koh *et al*, 2015); metal fume fever
Aluminium	TWA = 5 mg/m^3	TWA = 1 mg/m^3	Respiratory irritant; adverse effects in the lungs and central nervous system
Barium, soluble	TWA = 0.5 mg/m^3	TWA = 0.5 mg/m^3	Eye, skin & GI irritant; muscular stimulant
Beryllium	TWA = 0.002 mg/m^3	TWA = 0.00002 mg/m^3 & STEL = 0.0002 mg/m^3	Metal fume fever;[11] beryllium sensitisation; a carcinogen; other chronic effects include damage to the respiratory tract
Boron oxide	TWA = 10 mg/m^3	TWA = 10 mg/m^3	Eye and respiratory irritant
Cadmium	TWA = 0.01 mg/m^3	TWA = 0.001 mg/m^3	Irritation of respiratory system, sore and dry throat, chest pain and breathing difficulty; chronic effects include kidney damage and emphysema; suspected carcinogen
Chromium (II & III) Chromium (VI)	TWA = 0.5 mg/m^3 TWA = 0.05 mg/m^3	TWA = 0.04 mg/m^3 TWA = 0.000007 mg/m^3	Increased risk of lung cancer; some individuals may develop skin irritation; some forms are known human carcinogens (Cr VI)
Cobalt	TWA = 0.05 mg/m^3	TWA = 0.02 mg/m^3	Irritant, fibrosis of the lung, sensitiser
Copper	TWA = 0.2 mg/m^3	TWA = 0.01 mg/m^3	Acute effects include irritation of the eyes, nose and throat, nausea and metal fume fever
Fluorides	TWA = 2.5 mg/m^3	TWA = 2.5 mg/m^3	Acute effect is irritation of the eyes, nose and throat; long-term exposures may result in bone and joint problems; chronic effects also include excess fluid in the lungs
Iron oxide	TWA = 5 mg/m^3	TWA = 5 mg/m^3	Siderosis, a benign form of lung disease caused by particles deposited in the lungs; acute symptoms include irritation of the nose and lungs - tends to clear up when exposure stops
Lead	TWA = 0.05 mg/m^3	TWA = 0.05 mg/m^3	Chronic effects to nervous system, kidneys, digestive system and mental capacity; can cause lead poisoning; ototoxic and therefore risk of hearing loss
Magnesium oxide	TWA = 10 mg/m^3	TWA = 10 mg/m^3	Respiratory irritant, metal fume fever
Manganese	TWA = 1 mg/m^3 & STEL = 3 mg/m^3	TWA = 0.02 mg/m^3 resp & 0.1 mg/m^3 inhal	Metal fume fever; chronic effects may include central nervous system problems; ototoxic and therefore risk of hearing loss
Molybdenum – soluble / insoluble	TWA = 5 mg/m^3 / TWA = 10 mg/m^3	TWA = 0.5 mg/m^3 / TWA = 10 mg/m^3 inhal & 3 mg/m^3 resp	Acute effects are eye, nose and throat irritation, and shortness of breath
Nickel – metal / soluble	TWA = 1 mg/m^3 / TWA = 0.1 mg/m^3	TWA = 0.1 mg/m^3	Acute effect is irritation of the eyes, nose and throat; increased cancer risk has been noted in occupations other than welding; also associated with dermatitis and lung problems
Pyrolyzed rosin	TWA = 0.1 mg/m^3	TWA = 0.1 mg/m^3	Respiratory and/or skin irritant
Silica fume	TWA = 2 mg/m^3	TWA = 2 mg/m^3	Fever, similar to metal fume fever
Tin	TWA = 2 mg/m^3	TWA = 2 mg/m^3	Stannosis, a rare benign form of lung disease caused by particles deposited in the lungs
Titanium dioxide	TWA = 10 mg/m^3	TWA = 1 mg/m^3	Mild respiratory irritant
Vanadium	TWA = 0.05 mg/m^3 (as V_2O_5 resp)	TWA = 0.05 mg/m^3 (as V_2O_5 resp)	Acute effect is irritation of the eyes, skin and respiratory tract chronic effects include bronchitis, retinitis, fluid in the lungs and pneumonia
Zinc oxide	TWA = 10 mg/m^3	TWA = 2 mg/m^3 & STEL = 10 mg/m^3	Metal fume fever, bronchitis

[11] Symptoms are similar to the flu and are often worse at the start of the week. Effects usually aren't long-lasting.

Attachment 2: Effect of process, consumable and parent metal composition on the assessment of exposure

Adapted from The Welding Institute's publication "Health risks from fume and gases during welding", including data from papers by Korczynski (2000), Matczak & Gromiec (2002) and by Tyagi *et al* (1998).

Process	Material	Indication of fume level	Nature of fume - assessment indicators
Gas welding	Mild steel	Below WESs except in poorly ventilated or confined space.	Carbon dioxide (CO_2), carbon monoxide (CO; reducing flame) nitrogen dioxide (NO_2).
Manual metal arc (MMAW)	Mild steel and low alloy (structural) steels	Generally more than WESs; 3 to 30 mg/m^3 in open workshop conditions; depends on operator variables. Tyagi *et al* found 1.6 to 9.5 mg/m^3 for total fume, 1.5 to 2.4 mg Fe/m^3, and 0.5 mg Mn/m^3.	Iron oxide (Fe_2O_3), manganese (Mn).
	Stainless steel	Generally more than WESs; 3 to 30 mg/m^3 in open workshop. Tyagi *et al* found 1.4 to 14 mg/m^3 for total fume, and 0.3 mg Cr/m^3.	Hexavalent chromium (Cr VI) or nickel (Ni). Fume from consumables, may contain up to 8% chromium, the majority present as Cr VI.
	Aluminium, copper, nickel alloys, cast iron	Generally more than WESs.	Fume from consumables, ozone in aluminium welding. Aluminium, copper, nickel, chromium barium cobalt, depending on the alloy welded.
	Hardfacing	Generally more than WESs. Tyagi *et al* found 46 to 258 mg/m^3 for total fume, 16 mg Cr/m^3 and 9 mg Cr(VI)/m^3.	Fume from consumables, and ozone.
Gas tungsten arc (GTAW), or tungsten inert gas (TIG), and plasma arc	Mild and low alloy (structural) steels	Less than WESs.	Fume from consumables - shielding gas can constitute a hazard in confined spaces by reducing the available oxygen to a level that will not support life.
	Stainless steel alloys	Less than WESs for particulate fume (Tyagi *et al* found <1 mg/m^3), greater than WES for ozone.	Ozone, shielding gases in confined spaces.
	Aluminium	Less than WESs. Matczak & Gromiec found 0.3 to 1.4 mg/m^3 for total fume, 0.07 to 0.5 mg Al/m^3 for TIG.	Fume from consumables.
Gas metal arc (GMAW) or Metal inert gas/metal active gas (MIG/MAG)	Mild and low alloy (structural) steels	Generally more than WESs. Tyagi *et al* found 2 to 65 mg/m^3 for total fume, 5 to 39 mg Fe/m^3, and 1 to 5 mg Mn/m^3. Korczynski found 0.04 to 16 mg Fe/m^3 and 0.01 to 4.9 mg Mn/m^3.	Particulate Fe_2O_3, Mn, ozone, shield gases. Higher fume levels are obtained with CO_2 shielding than with argon.
	Stainless steel	Generally more than WESs. Tyagi *et al* found 5 to 29 mg/m^3 for total fume, and 2 mg Cr/m^3.	Cr, Ni, ozone and shield gases. Process related values will apply to particulate fume.
	Aluminium and aluminium alloys	Greater than WESs for ozone and fume. Tyagi *et al* found <1 to 94 mg/m^3 for total fume, 6 to 44 mg Al/m^3, 0.3 mg Mn/m^3, 0.2 to 0.4 mg Zn/m^3 and up to 1.2 ppm ozone. Matczak & Gromiec found 0.8 to 18 mg/m^3 for total fume, 0.1 to 7.7 mg Al/m^3, 0.002 to 0.05 mg Mn/m^3, 0.002 to 0.14 mg Zn/m^3.	Particulate aluminium oxide fume. Ozone levels can be very high particularly with aluminium/silicon alloys some distance from the arc.

Process	Material	Indication of fume level	Nature of fume - assessment indicators
Flux-cored arc (FCAW)[12]	Mild and low alloy (structural) steels	Generally more than WESs. Tyagi *et al* found 4 to 290 mg/m^3 for total fume, 7 to 140 mg Fe/m^3, and 0.4 to 32 mg Mn/m^3.	Particulate Fe_2O_3, Mn and flux materials, some consumables may give rise to soluble barium in fume.
	Stainless steel	Greater than WESs.	Consumable and flux particulates, Cr VI, Cr III, Ni likely to be present.
	Hardfacing	Generally more than WESs. Tyagi *et al* found 32 to 345 mg/m^3 for total fume, 0.9 to 27 mg Cr/m^3 and 0.2 to 1.3 mg Cr(VI)/m^3.	Fume from consumables, chromium VI likely to be present.
Brazing	Copper and brass	Generally below WESs. Tyagi *et al* found <0.6 mg/m^3 for total fume, and 2.7 mg F/m^3.	Copper (Cu), zinc (Zn) and fluoride (F) particulate fume.
Thermit	Rail steel	Generally greater than WESs for fume. Tyagi *et al* found <2 to 159 mg/m^3 for total fume.	Particulate fume.

[12] Note that self-shielded FCAW produces more fume that does gas shielded FCAW.