Welding Fumes

Patti C. Erdely, PhD

The findings and conclusions in this report are those of the author and do not necessarily represent the official position of the National Institute for Occupational Safety and Health.
Outline

- Background
- Welding hazards
- Health hazards (humans and animal models)
- IARC
- Current/future research
- Exposure limits/assessments
- Summary
Occupational Safety and Health at the Federal level

Regulation, Enforcement, Consultation

- U.S. Department of Labor (DOL)
  - Mine Safety and Health Administration (MSHA)
  - Occupational Safety and Health Administration (OSHA)

Research and Recommendations

- U.S. Department of Health and Human Services (HHS)
  - Centers for Disease Control and Prevention (CDC)
  - National Institute for Occupational Safety and Health (NIOSH)
What is welding?

- Common industrial process in the U.S. and worldwide used to join metals and alloys that have been made soft or liquid by extreme heat
  - Upon cooling and solidification, a metallurgical bond results

- Welding (broadly classified) as gas or arc welding
  - Focus on arc welding versus gas (uses fuel gases such as acetylene to generate heat)

- Arc welding: uses electric current to form an electric arc between the electrode (consumable) and the metals to be joined
What is welding cont...

• Metal Inert Gas (MIG or Gas Metal Arc Welding/GMAW), Tungsten Inert Gas (TIG), Stick or Arc (Shielded Manual Arc Welding/SMAW or Manual Metal Arc), Flux Core Arc Welding (FCAW)
  – 80–90% of all manufacturing and maintenance welding
  – SMAW most common worldwide

• Flame cutting typically grouped occupationally with welding
  – Oxygen and a fuel gas are used to cut metal
  – Other processes closely related to welding and often done by welders: gouging, brazing, carbon arc cutting, soldering

• Fluxes and shielding gas are for weld protection
  – Flux- rutile Titanium dioxide, calcium fluoride, cellulose, iron powder
  – Gases- helium, argon, carbon dioxide, nitrogen, or a gas mix
What is welding fume?

- **Welding aerosols** – complex aerosol mixture of gases and metal-rich particulate matter
  - Gases generated/used considered to have a minimal role in toxicity

- **Welding fume** – heat metals above their melting point, vaporize, and condense into a fume (=particle)
  - Fume – most people think “gas” or “vapor” but actually very small, solid particles suspended in the air
  - Can contain particles from the base metal, wire/electrode, and coatings on the base metal
  - Most complex occupational exposure known
Particle Morphology

- Particle size is generally <1 μm and reach into the deep lung regions
  - Agglomerates of chain-like aggregates
- Incidental nanoparticle – large number of <0.1 μm particles formed
# Metal Composition of Welding Fume

<table>
<thead>
<tr>
<th>Welding Fume Sample</th>
<th>Metal (weight %)</th>
<th>Soluble/Insoluble Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMA-MS, Gas metal arc-mild steel</td>
<td>Fe 85, Mn 14</td>
<td>0.020</td>
</tr>
<tr>
<td>GMA-SS, Gas metal arc-stainless steel</td>
<td>Fe 57, Mn 13.8, Cr 20.2, Ni 8.8</td>
<td>0.006</td>
</tr>
<tr>
<td>MMA-SS, Manual metal arc-stainless steel</td>
<td>Fe 41, Cr 29, Mn 17, Ni 3</td>
<td>0.345, Soluble metals: Cr 87%, Mn 11%</td>
</tr>
</tbody>
</table>
Industries We Serve

AUTOMOTIVE/TRANSPORTATION
Automotive manufacturers require stronger, lighter and more exotic materials to withstand manufacturing processes.

HEAVY FABRICATION
Robust advanced power sources and processes are ideal for heavy equipment.

OFFSHORE
Welding products for harsh environments including construction, maintenance and repair of drilling, production, pipelines, infrastructure, desalination, surface and supply vessels.

PIPE MILL
Cost-effective welding solutions to perform single or multi-pass welding on 380 grade pipes or multiple-pass processes or higher strength materials for the pipes and mills industry.

LNG
Welding tanks for the transportation and storage of LNG requires robust power sources and superior, quality-tested consumables.

PRESSURE VESSEL
Pressure vessel fabrication for power generation industries requires process knowledge that far exceeds other applications.

WIND POWER
The demand for wind tower fabrication has become more prominent and requiresmovable power resources and global technical support.

STRUCTURAL
Welding technology and performance is the structural steel industry to order. Often fabricating structures like bridges and skyscrapers.

GENERAL FABRICATION
Robust power sources and processes knowledge to help you get your welding job done right in the shop, field, or garage.

MAINTENANCE & REPAIR
Innovative and repair wear across industries such as mining, agriculture and processing.

PIPELINE
Integrated solutions to meet growing demand of pipeline industry to rehabilitate existing infrastructure and satisfactorily enable new creativity and robust pipeline.

POWER GENERATION & PROCESS
Fabrication, construction, and maintenance of wind turbines, thermal and nuclear plants, LPG tank and pressure vessels for energy and process industries.

NUCLEAR
Increased interest in nuclear power is increasing the demand for products designed to meet the strict requirements of the nuclear industry.

THERMAL ENERGY
Industrially minded, welding products are instrumental for coal-fired, natural gas or combined cycle thermal energy power plants across the country.

SHIPBUILDING
Increased productivity drives the need for efficient, rugged, and transportable welding solutions in the highly competitive shipbuilding industry.

ASK THE EXPERTS
Get help from Lincoln Electric welding experts. Contact Us

http://www.lincolnelectric.com/en-us/industries/Pages/industries.aspx
Welding in the Electric Industry

Electrician
Location: Haywood, WV, US, 26366-0600
Job Function: Maintenance
Employee Type: Reg Full Time (FT)
Requisition ID: 3781

FirstEnergy at a Glance

FirstEnergy (NYSE: FE) is dedicated to safety, reliability and operational excellence. Headquartered in Akron, Ohio, FirstEnergy includes one of the nation’s largest investor-owned electric systems, more than 24,000 miles of transmission lines that connect the Midwest and Mid-Atlantic regions, and a diverse generating fleet with a total capacity of nearly 17,000 megawatts.

Example duties:
- Installation of electrical equipment and raceways, including support structures; performing non-code welding, brazing, soldering, electric arc welding and oxyacetylene burning.
- Maintaining and repairing storage batteries, battery changing equipment and uninterruptable power systems (UPS).
- Coordinating with supervisors and production crew for clearance and removal of equipment from service, both mechanical and electrical, isolation and de-isolation of equipment per the tagging procedures.
- Performing rigging, tackle, blocking, scaffolding, ladders, and moving heavy parts and equipment. Directs the movement and lifting of heavy equipment.
- Taking oil samples and maintaining oil levels in motors, transformers, and transformer rectifiers (TR) sets.
- Maintaining and repairing controls on auxiliary equipment, including programmable logic controllers (PLC's).
- Performs hydraulic and pneumatic repair work.
- Performing tasks assigned for continuity or restoration of service in an emergency.
- Performs non-code welding, brazing, soldering, electric arc welding and oxyacetylene burning.
Maintenance Mechanic
Location:  Shippingport, PA, US, 15077
Job Function:  Maintenance
Employee Type:  Reg Full Time (FT)
Requisition ID:  4101

Responsibilities:
Under general directive supervision, works with and directs up to three (3) employees in performing skilled mechanical repair work on all plant equipment (air compressors, turbines, generators, pumps, fans, air heater, blowers, etc.); all mechanical equipment (boilers, pulverizers, feeders, heat exchangers, condensers, valves, etc.); and all plant auxiliary equipment (yard equipment, power piping, etc.). Mechanical work includes assembly, non-code welding, sheet metal work, pipe fitting, machining and rigging.

Example duties
•  Performs rigging, dismantling, overhauling, repairing, testing, and assembling of rotating, mechanical, and plant auxiliary equipment; operating overhead and mobile cranes on regular and precision lifts.
•  Makes or reproduces special parts, assemblies, tools, jigs and fixtures; making necessary measurements and sketches.
•  Operates and maintains hand tools; operates shop tools; perform drilling, grinding, cutting, shearing, filing, bending, forming and chipping.
•  Aligns rotated equipment assemblies using dial indicator technique.
•  Performs non-code welding, brazing, soldering, electric arc welding and oxyacetylene burning; layouts, fabricates and maintains plant piping; prepares materials for and depositing metal surfaces on parts.
Garage Mech 1st Cl
Location: Altoona, PA, US, 16602
Job Function: Transportation
Employee Type: Reg Full Time (FT)
Requisition ID: 585

Responsibilities include:
• Under direct or general supervision regularly and customarily inspects, repairs, and maintains all types of the Company's transportation units and their parts and accessories. This includes any of the following, with other related and incidental work:
• Performs any or all of the most difficult repairs, replacements, and adjustments to automotive parts, assemblies and equipment; including auxiliary apparatus such as air compressors, door mechanisms, windshield wipers, electrical systems and so on.
• Rebuilds and repairs truck bodies and cabs, seats, bumpers and other attachments.
• Operates power tools and does incidental welding in connection with the performance of major duties.
• Is responsible for the proper clerical record of all work accomplished and parts and supplies used.
• Makes roadside repairs when necessary.
• Upon occasion or in emergency performs other related or less skilled work as required or directed.
Welding Hazards
Potential Health Hazards

**FUMES:**

*Alloys*
Aluminum (conducive to high fume formation rates and ozone production)
Chromium (stainless steel alloy, lung carcinogen)
Copper (metal fume fever)
Iron (most common fume component, siderosis)
Lead (brass and bronze alloy, neurotoxin)
Magnesium
Manganese (neurotoxin, respiratory irritant)
Molybdenum
Nickel (stainless steel alloy, lung carcinogen)
Tin (bronze and solder alloy, metal fume fever)
Zinc (galvanized steel and paint coatings, metal fume fever)

*Fluxing agents*
Barium, Fluorine, Silicon, Titanium

**GASES:**

Ozone ($O_3$; lung irritant; formed when arc UV light reacts with atmospheric $O_2$)
Nitrogen Oxides (NO, NO$_2$; lung irritant; formed by oxidation of atmospheric nitrogen)
Carbon Monoxide (CO; highly toxic; at high arc temperatures $CO_2$ is reduced to more stable CO)
Phosgene (formed when arc UV light reacts with metal-cleaning chlorinated hydrocarbons)

**OTHER:**

Heat
Noise
Vibration
Electromagnetic fields (EMF; welding power source/cables)

**ELECTROMAGNETIC RADIATION (EMR):**

Ultraviolet (10 to 400 nm)
Visible (400-700 nm)
Infrared (700 nm to 1 mm)

MIG Robotic Welder at NIOSH

GMA-SS Fume Characterization

(a) and (b) Images of the fume particles under SEM.

(c) Particle size distribution histogram.

(d) SMPS estimated aerodynamic diameter.

Pulmonary Hazards of Welding Fume in Humans

Metal fume fever (#1 acute)
- 30 to 40% estimated occurrence
- Symptoms
  - Flu-like
  - Dyspnea
  - Cough
  - Muscle pain
  - Fever
  - Chills
Pulmonary hazards cont...

§ Bronchitis (#1 chronic)
- Characterized by airway inflammation
- Increased prevalence of chronic bronchitis in welders
  • Defined as cough and mucus expectoration on most days for 3 months or more out of the year

§ Siderosis or Welders’ pneumoconiosis
Respiratory Infection/Immunological Hazards of Welding Fume

§ Humans

- Increases severity, frequency, and duration of upper and lower respiratory tract infections (Lockey et al., Am Rev Respir Dis. 1988 138; 1047-1050)
- Very real risk of welders dying from pneumococcal and unspecified lobar pneumonia
  - 2011- UK Dept. of Health’s Green Book recommended pneumococcal vaccination for welders
    § One theory- the ultrafine particles (<100 nm) in welding fume promote adherence of pneumococci to the bronchial epithelium; ferrous metal seems most apparent for risk
§ Animals

- Body of work from experimental models that support the theory that welding fumes compromise immunity
- Show a reduced ability to combat a secondary infection after exposure
  • Antonini et al., *Toxicol Appl Pharmacol.* 2007 & *Inhal Toxicol.* 2009 - where inhalation of both GMA-SS and GMA-MS fumes reduced bacterial (*L. monocytogenes*) clearance from the lung
- Indicate systemic immune deficiency
  • Erdely et al., Particle and Fibre Toxicology. 2014 11:34.
  § Found that the reduced pulmonary leukocyte response that was observed with bacterial challenge in previous studies was from a systemic dysfunction
Inflammatory lung effects in animals by fume type

§ Intratracheal instillation studies in rats and mice
- Pulmonary inflammation and tumor induction in lung tumor susceptible A/J and resistant C57BL/6J mice exposed to welding fume. Zeidler-Erdely et al., *Particle and Fibre Toxicology* 2008.

§ Overall conclusions of animal studies
- Soluble SS (MMA-SS) > Insoluble SS (GMA-SS) > MS in terms of lung toxicity (inflammation, oxidant production, etc)
- This also holds true *in vitro* and confirmed with inhalation exposures (GMA-SS>GMA-MS)
Welding fume not just a respiratory hazard
Neurological Hazards of Welding Fume

§ Primarily concerned with Mn overexposure or low-level chronic exposure
  - cause damage to the CNS and other organs

§ Low levels of Mn (<0.2 mg/m\(^3\)) in welding fumes
  - changes in mood and short-term memory, altered reaction time, and reduced hand-eye coordination; affected workers frequently show abnormal accumulations in the globus pallidus (regulates movement)

§ Prolonged exposure to high concentration (>1 mg/m\(^3\)) can lead to “manganism”
  - Have Parkinson-like symptoms - tremors, slowness of movement, muscle rigidity, and poor balance
Neurological Toxicity Research

Humans

§ Sequelae of fume exposure in confined space welding: a neurological and neuropsychological case series. (Bowler et al., Neurotoxicology. 2007 Mar; 28(2): 298-311.)
   - Welders in the construction of the new Bay Bridge (San Francisco); welded in confined spaces for up to 2 years; minimal protection; poor ventilation
   - among 43 welders - 11 cases of manganism

§ Neurologic manifestations in welders with pallidal MRI T1 hyperintensity. (Josephs et al., Neurology. 2005 Jun 28;64(12):2033-9.)
   - male career welders with increased T1 basal ganglia signal on MRI of the brain; parkinsonian syndrome (three patients), a syndrome of multifocal myoclonus and limited cognitive impairment (two patients), a mixed syndrome with vestibular-auditory dysfunction (two patients), and minor subjective cognitive impairment, anxiety, and sleep apnea (one patient)
   - Also welding without proper protection

Animal Models

§ Mitochondrial dysfunction and loss of Parkinson’s disease-linked proteins contribute to neurotoxicity of manganese-containing welding fumes. (Sriram et al., FASEB J. 2010 Dec;24(12):4989-5002. doi: 10.1096/fj.10-163964.)

§ Modifying welding process parameters can reduce the neurotoxic potential of manganese-containing welding fumes. (Sriram et al., Toxicology 2015 Feb 3;328:168-78. doi: 10.1016/j.tox.2014.12.015.)
Cardiovascular Hazards of Welding Fume

- Epidemiologic studies indicate that there is increased risk of adverse cardiovascular effects following inhalation of air pollution/particulate matter
- Effects are more likely in compromised individuals
  - Elderly, Pre-existing condition, etc.,
  - Chronic exposures can contribute to adverse effects
- Welding fume represents a metal-rich particulate matter
Cardiovascular Toxicity Research

Humans

$ Vascular function, inflammation, and variations in cardiac autonomic responses to particulate matter among welders. (Fang et al., *Am J Epidemiol* 2009 Apr 1;169(7):848-56. doi: 10.1093/aje/kwn405.)

$ Acute changes in vascular function among welders exposed to metal-rich particulate matter. (Fang et al., *Epidemiology* 2008 Mar;19(2):217-25. doi: 10.1097/EDE.0b013e31816334dc.)


Animal Models


Summary

§ Welding fume is a metal-rich particulate matter with a significant amount of ultrafine particles generated
  - The gases generated or used during welding processes are not the major source of toxicity
§ Welding fume is linked to adverse cardiovascular events
§ Welding fume may induce neurological effects
  - There is still debate whether there is actually an increased risk of Parkinson’s disease (or early onset) but manganism can occur especially if poor protection
    • https://app.aws.org/duke_study/
§ Welding fume exposure is primarily associated with respiratory hazards in humans and animals
  - This is well-documented and studies in humans and experimental animal models
Lung Cancer

§ General concepts of lung cancer
  - Leading cause of cancer death in the US, among both men and women
    • In 2014, ~527,228 people living with lung and bronchus cancer in the US
    • 222,500 estimated new cases in 2017
    • 13.2 % of all new cancer cases

§ Risk factors
  - Environmental
    • People who smoke have the greatest risk
    • Exposure to secondhand smoke; living where there is significant air pollution
  - Family history
  - Occupational Exposures
    • Asbestos, chromium, arsenic, nickel, etc.
  - Viral exposures (HIV)
  - Risk increases as you age; when you smoke and have one of these other risk factors

International Agency for Research on Cancer (IARC) Structure

§ Who participates?
- The Working Group – invited experts by IARC
- Invited Specialists - experts with critical knowledge (but have conflicts of interest, non-participatory)
- Representatives of national and international health agencies (sponsor the program, non-participatory)
- Observers
- The IARC Secretariat (scientists with relevant knowledge, participate)

§ Meeting is scheduled as 7 days
- Volume 118 – ‘Welding, Welding Fumes and Some Related Chemicals’; 21-28 March 2017; Lyon, France
The Working Group

- Verify all pertinent studies are included
- Select studies relevant for evaluation on basis of merit
- Prepare accurate summaries
- Evaluate results and note strengths/limitations
- Prepare preliminary evaluations for each agent
The Working Group

§ Preparation before is drafts, rewrites, peer review
  - Usually 7-8 months prior

§ Four subgroups:
  - Subgroup 1 - Exposure data
    • New estimate that ~11 million workers have the job title “welder” and ~110 million additional workers incur welding-related exposures
  - Subgroup 2 - Cancer in humans
    • 100 publications
  - Subgroup 3 – Cancer in experimental animals
    • 6 publications
  - Subgroup 4 - Mechanisms
    • 250 publications (not necessarily all cited); evidence judged as weak, moderate, or strong; “not classified”
The Evidence – in humans

§ The carcinogenicity evidence in humans:
- Sufficient
  • Causal relationship has been established (chance, bias, and confounding ruled out)
- Limited
  • Positive association has been observed, but causal interpretation credible but chance, bias, or confounding could not be ruled out
- Inadequate
  • Studies cannot be interpreted as showing either presence or absence of effect because of major limitations or no data are available
- Lack
  • Several adequate studies consistently showing no positive association between the agent and cancer
The Evidence – in animals

§ The carcinogenicity evidence in animals:

- Sufficient
  - Causal relationship has been established between the agent and neoplasms in 2 or more species or 2 or more independent studies in one species (different times or labs); or one GLP study with increase in both sexes

- Limited
  - Data is suggestive but only one experiment; experimental design potentially inadequate; increases only benign neoplasms; tumor promoting activity only

- Inadequate
  - Studies cannot be interpreted because of design flaws; no data in animals is available

- Lack
  - Adequate studies of at least 2 species consistently showing no positive association between the agent and cancer
IARC Classifications

§ Group 1: The agent is carcinogenic to humans
  - Sufficient in humans; can be less than sufficient in animals

§ Group 2A: Probably carcinogenic to humans
  - Limited in humans and sufficient in animals; also inadequate in humans and sufficient in animals (mechanistic evidence has to be strong)

§ Group 2B: Possibly carcinogenic to humans
  - Limited in humans and less than sufficient in animals; inadequate in humans and sufficient in animals

§ Group 3: Not classifiable
  - Inadequate in humans and animals (or limited in animals)

§ Group 4: Probably not carcinogenic
  - Evidence suggesting lack of carcinogenicity in humans and experimental animals
Welding Fumes as of 1990


§ Welding fumes Group 2B or “possibly carcinogenic” to humans
  - *Inadequate* animal evidence (only 2 studies)
  - *Limited* epidemiology and difficulty in studying welder populations (heterogenous worker population; co-exposures; duration of exposure, etc.)

§ Welding fume as a *high priority agent* for further evaluation of carcinogenic risk to humans
  - 2010-2014 advisory group on IARC Monograph priorities
  - Occupation as a welder excess lung cancer risk of 20-40%
Carcinogenicity of welding, molybdenum trioxide, and indium tin oxide

**Group 1:****

- **Lung cancer** – Sufficient in humans and limited in animals
- **Ocular melanoma** - Sufficient in humans
- Positive association with **kidney cancer** - reported in nearly all relevant cohort and case–control studies (few studies adjusted for solvents used for cleaning metal in tandem with welding, such as trichloroethylene (a risk factor for kidney cancer). Increased risks were consistently reported across countries, occupational settings, and study designs (chance, bias, and confounding could not be ruled out)
Lung Cancer Epidemiology

Cohort studies:
  - Danish cohort; Exposure-response relationship for stainless steel welders only

Case-control studies:
  - Large, multi-center study; increased OR for gas welding > arc welding;
  - Working group determined as one of the most informative on welding and lung cancer; job-title based analysis that included all relevant adjustments (age, jobs known to be associated with lung cancer, etc.); increased OR with duration of welding
- ICARE study, a population-based case-control study, found that welding and mode of workpiece preparation are important determinants of lung cancer risk in welders (Matrat et al., 2016, *Occup Environ Med*. Doi: 10.1136/oemed-2015-102964)
  - Among regular welders, a frequency of welding >5% of working time was associated with a 70% increase in risk of lung cancer
Ocular Melanoma

- Arc welding generates UV radiation, a risk factor for the rare cancer ocular melanoma
- Ocular disorders (e.g., cataracts or keratoconjunctivitis) occur in both welders and nearby workers
- **Sufficient evidence** for the carcinogenicity of UV radiation from welding came from eight partly overlapping case–control studies and two census-based cohort studies
  - Risks of developing ocular melanoma generally increased by between 2-10 fold.
  - Risks persisted after adjustment for sun exposure, sun bed use, or both
Mechanisms of Cancer

§ Initiators
- Mutagens that predispose cells to tumor development and increase risk of tumors
- Cause permanent genetic change

§ Promoters
- Compounds that stimulate tumor development
- Susceptible to an initiator’s effects and promote cell proliferation
- No effect without initiator
Previous research in Erdely lab

<table>
<thead>
<tr>
<th></th>
<th>Lung Tumor Multiplicity</th>
<th>Lung Tumor Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>48 wk</td>
<td>78 wk</td>
</tr>
<tr>
<td>Sham</td>
<td>0.38±0.13 (21)</td>
<td>1.00±0.35 (19)</td>
</tr>
<tr>
<td>GMA-MS</td>
<td>0.42±0.14 (24)</td>
<td>1.00±0.22 (20)</td>
</tr>
<tr>
<td><strong>GMA-SS</strong></td>
<td><strong>0.45±0.14 (20)</strong></td>
<td><strong>1.75±0.32 (16)</strong></td>
</tr>
<tr>
<td>MMA-SS</td>
<td>0.25±0.11 (24)</td>
<td>1.55±0.34 (20)</td>
</tr>
</tbody>
</table>


- Tested as an initiator
- GMA-SS fume caused greatest increase in tumor incidence/multiplicity but not different from sham
- Increased persistence of GMA-SS fume triggers chronic inflammatory state in the lung compared to other fumes which may enhance tumorigenesis
Two-stage Lung Cancer Animal Model

Welding fume (40 mg/m³) or air inhalation (4 h/d x 4 d/w x 9 w)

MCA or corn oil 10 µg/g IP

0 1 9 30
Weeks

Tumor multiplicity/incidence

Tumor Number

CO/Air  CO/GMA-SS  MCA/Air  MCA/GMA-SS

GMA-MS Welding Fumes
Individual Metals and Lung Toxicity

Component results – ongoing research
- Iron has a promoter effect in mice
  • This agrees with the epidemiology for welders and GMA-MS results
- It appears that while Cr and Ni have no effect, the total GMA-SS fume has greater toxicity than Fe alone
  • there is an additive/synergistic effect in combination with all components

Falcone, LM. et al., in preparation.
Exposure limits

- American Conference of Governmental Industrial Hygienists (ACGIH) withdrew the Threshold Limit Value (TLV) of 5 mg/m³

- Occupational Safety and Health (OSHA) – not yet set a permissible exposure limit (PEL) for welding; 5 mg/m³ was challenged in 1989 and no longer enforced
  - OSHA fact sheet for welding CrVI PEL (5 µg/m³ TWA); other guidelines for ventilation; surface cleaning, etc. to reduce exposure

- Possibly regulate on specific toxic metal (e.g. CrVI, Mn)
  - Mn TLV (revised 2013 by ACGIH) : inhalable - 0.1 mg/m³; respirable – 0.02 mg/m³ (previous was 0.2); OSHA 5 mg/m³ (ceiling)
  - CrVI- OSHA 5 µg/m³ ; NIOSH 0.2 µg/m³
### Exposure Guidelines for Materials Sometimes Found in Welding Fume

<table>
<thead>
<tr>
<th>Material</th>
<th>ACGIH(1) TLV (mg/m3)</th>
<th>OSHA(2) PEL (mg/m3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welding Fume</td>
<td>5.0</td>
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</tr>
<tr>
<td>Iron Oxide, as Fe</td>
<td>5.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Manganese (all forms)</td>
<td>0.2</td>
<td>1.0(3) 5.0 (c)</td>
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<tr>
<td>Chromium III compounds</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Chromium VI compounds, sol</td>
<td>0.05</td>
<td>0.05 (c)</td>
</tr>
<tr>
<td>Chromium VI compounds, insol</td>
<td>0.01</td>
<td>0.5 (c) NIC .0005 - .005 (both forms)</td>
</tr>
<tr>
<td>Nickel, insol compounds, as N</td>
<td>(1.0) 0.5 NIC</td>
<td>1.0</td>
</tr>
<tr>
<td>Aluminum, Welding Fumes, as Al</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>Zinc Oxide, fume</td>
<td>5.0 10.0 (c)</td>
<td>5.0</td>
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<tr>
<td>Barium compounds, sol, as Ba</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>Beryllium &amp; compounds, as Be</td>
<td>0.002 .01(c)</td>
<td>0.002 .005(c)</td>
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<tr>
<td>Cadmium Oxide, as Cd</td>
<td>0.002</td>
<td>0.005</td>
</tr>
<tr>
<td>Cobalt oxide, as Co</td>
<td>0.02</td>
<td>0.1</td>
</tr>
<tr>
<td>Copper fume, as Cu</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Flourides, as F</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Magnesium oxide fume</td>
<td>10.0</td>
<td>15.0 total particulate</td>
</tr>
<tr>
<td>Molybdenum, insol compounds, as Mo</td>
<td>10.0</td>
<td>15.0 total particulate</td>
</tr>
<tr>
<td>Tin oxide</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Vanadium pentoxide, as V2O5</td>
<td>0.05</td>
<td>0.1(c)</td>
</tr>
</tbody>
</table>

(1) Threshold Limit Value set by ACGIH (American Conference of Governmental Industrial Hygienists) based upon 8 hour TWA (Time Weighted Average), as of 9/98.
(2) OSHA Permissible Exposure Limit based upon 8 hour TWA, as of 9/98.
(3) Short Term Exposure Limit (STEL) for Manganese, based on a 15 minute TWA, is 3 mg/m3
(c) Maximum Exposure Concentration: not to be exceeded at any time (not a TWA).

Exposure Assessment

§ Fume type
- Stainless steel levels range from < 1 mg/m3 to over 25 mg/m3
  • Lowest from GTAW and highest from MMA
- Mild steel levels range from < 1 mg/m3 to over 50 mg/m3
  • Lowest from GMAW and highest MMA and FCAW

§ Country
- Higher levels in Finland and US
- Lower levels in Canada, UK, and New Zealand

§ Industry
- Highest in manufacturing and lowest in automobile

§ Trades
- Highest for boilermakers and lowest for pipe and welder fitters

§ Ventilation
- Lowest for mechanical and local exhaust ventilation
- CrVI concentrations vary significantly with welding type and shield gas type; presents an opportunity to tailor welding practices to lessen CrVI exposures; short-circuit processes generated less CrVI than axial-spray methods; inert gas shielding gave lower Cr(VI) content than shielding with active gases

- Different voltage settings modified the elemental composition and particle size, affected the lung toxicity in rats after inhalation

Summary

- Our ongoing research suggests both mild steel and stainless steel fumes have tumor promoter effects in an animal model.

- Future toxicology research will continue to look at process modifications and “new” electrodes:
  - Currently doing a Ni-Cu electrode study.

- IARC:
  - Welding fume a Group 1 carcinogen (carcinogenic to humans) for lung, ocular melanoma, and a positive association for kidney:
    - Lung based on limited animal but sufficient human evidence.
  - New estimates of total worker population being over 110 million.
NIOSH Resources

Health Hazard Evaluation Reports
- searchable database
https://www2a.cdc.gov/hhe/search.asp

Topic page on welding and manganese
https://www.cdc.gov/niosh/topics/welding/default.html

Index of Chemical names
https://www.cdc.gov/niosh/pel88/welding.html
- index of chemical names, information about exposures and limits

CIB 68 – NIOSH Chemical Carcinogen Policy
https://www.cdc.gov/niosh/docs/2017-100/pdf/2017-100.pdf

RTECS (NIOSH Registry of Toxic Effects of Chemical Substances)
https://www.cdc.gov/niosh-rtecs/ZC26E8F0.html
- last updated May 2009
Other Resources for Welding Fume

OSHA
  - fact sheet for welding

https://www.osha.gov/dts/chemicalsampling/data/CH_276100.html
  - needs updated, still listed as a group 2B on website

Lincoln Electric
  - information on exposure limits (although dated), definition of welding fume, reducing exposures
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