Welding Fumes: An Occupational Health Perspective

Speaker:

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Occupational Hygienist
Outline

- Introduction to OHCOW
- Overview of the workforce
- Basics of welding and welding Fume
- Size fraction of the Particulate Matter
- Health hazards and medical surveillance
  - Adverse health effects of welding exposure
    - Manganese
    - Hexavalent Chromium
    - Nickel
    - Iron
    - Beryllium
- Welding Fume Exposure Prevention Strategies
Occupational Health Clinics for Ontario Workers (OHCOW)

7 Clinics

- Hamilton, 1989
- Toronto, 1989
- Windsor, 1991
- Sudbury, 1992
- Sarnia, 1999, 2004
- Thunder Bay, 2010
- Ottawa, 2016
Occupational Health Clinics for Ontario Workers

Multi-disciplinary Occupational health team:

- Client Service Coordinators
- Occupational medicine physicians
- Occupational health nurses
- Ergonomists
- Occupational hygienists
OHCOW Services

1. Individual client (clinical)
2. Enquiry (Occupational health/illness related)
3. Informational presentations
4. Workplace visits
   - requested by co-chairs of JH&SC
5. Intake Clinic/health investigations
   - medical/hygiene/ergonomic combined
   - research projects

J

Occupational Health Clinics for Ontario Workers Inc.
Welding and the workforce

• Over 11 million workers are directly and 110 million indirectly exposed to welding fumes worldwide (IARC 2017).

• 754,000 welders in USA (AWS 2021)

• Approximately 1 million welders in North America.

OSHA fact sheet: Controlling Hazardous Fume and Gases During Welding
Highly exposed workers

333,000 WORKERS (EST.)

WELDING FUMES EXPOSURE IN CANADA

<table>
<thead>
<tr>
<th>FIVE LARGEST EXPOSURE GROUPS BY INDUSTRY</th>
<th>PROPORTION OF INDUSTRY EXPOSED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machinery and equipment repair and maintenance*</td>
<td>26,000</td>
</tr>
<tr>
<td>Building equipment contractors</td>
<td>25,000</td>
</tr>
<tr>
<td>Automotive repair and maintenance</td>
<td>22,000</td>
</tr>
<tr>
<td>Motor vehicle parts manufacturing</td>
<td>16,000</td>
</tr>
<tr>
<td>Architectural and structural metals manufacturing</td>
<td>15,000</td>
</tr>
</tbody>
</table>

CAREX Canada: [Welding Fumes - Occupational Exposures - CAREX Canada](#)
Intensity of exposure

CAREX Canada: Welding Fumes - Occupational Exposures - CAREX Canada
Burden of occupational cancer

- 1.3% of lung cancer cases and 5.4% ocular melanomas diagnosed annually.
- Work related lung cancers from welding fumes costed $308 million in 2011.

Lung Cancer | Symptoms, Causes, Treatment and Survival Rates (drugwatch.com)
Welding Basics

- Welding = process that uses heat generated by electricity (arc welding) or fuel gases (oxyfuel welding) to fuse metal materials.

- Based on the source of heat, welding is broadly classified into Arc welding and gas welding.
<table>
<thead>
<tr>
<th>Welding type</th>
<th>Primary exposures encountered</th>
<th>Common industrial uses</th>
<th>Most common base metals welded</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxyfuel</td>
<td>$\text{NO}_2$</td>
<td>Repair/ maintenance</td>
<td>MS$, SS, AS</td>
<td>Weman (2003), Moniz &amp; Miller (2010)</td>
</tr>
<tr>
<td>FCA</td>
<td>Metals, $\text{CO}_2$, UV radiation, ELF-EMF</td>
<td>Equipment repair, shipbuilding</td>
<td>MS$, SS, AS</td>
<td>Spiegel-Ciobanu (2010)</td>
</tr>
<tr>
<td>SA</td>
<td>Fluorides, UV radiation, ELF-EMF</td>
<td>Steel fabrication, shipbuilding</td>
<td>MS$, SS, AS</td>
<td>Weman (2003), Moniz &amp; Miller (2010)</td>
</tr>
<tr>
<td>Brazing/soldering</td>
<td>Metals, UV radiation</td>
<td>Metal arts, plumbing, electric components</td>
<td>All metals/steels</td>
<td>Moniz &amp; Miller (2010)</td>
</tr>
<tr>
<td>Cutting/gouging</td>
<td>Metals, O$_2$, NO$_2$, UV radiation</td>
<td>Fabrication, construction, shipbuilding</td>
<td>All metals/steels</td>
<td>Weman (2003), Moniz &amp; Miller (2010)</td>
</tr>
</tbody>
</table>

$^a$ Most common type welded

$^b$ Used historically as an insulating material in ships to insulate covered rod electrodes, in cylinders holding acetylene gas, and in heat-protective equipment of welders and the weld. Metals include but are not limited to: Fe, Mn, Al, Ni, Cr, K, Ba, Ca, F, Ti, Co, Zn, Mo, Pb, Mg, and As. These will vary by composition of base metal Al, aluminum alloys; AS, alloyed steel; CO, carbon monoxide; CO$_2$, carbon dioxide; ELF-EMF, extremely low-frequency electromagnetic fields; ER, electric resistance; FCA, flux cored arc; GMA, gas metal arc; GTA, gas tungsten arc; HC, hydrocarbon; MMA, manual metal arc; MS, mild steel; NO, nitric oxide; NO$_2$, nitrogen dioxide; O$_3$, ozone; SA, submerged arc; SS, stainless steel; UV, ultraviolet.
Welding Fume Composition

The composition and the amount of welding fume generated depends on the type of gas used for welding, welding rod materials, base material, metallic or paint coatings, welding process, and ventilation effectiveness.
Welding Fume Composition

- **Particulate matter**: Aluminium, antimony, Arsenic, Beryllium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Molybdenum, Nickel, Silver, Tin, Titanium, Vanadium, Zinc, Silicates, Fluorides.

- **Gases**: Shielding gases (Argon, Helium, nitrogen, Carbon Dioxide), Process gases (Nitric Oxide, Nitrogen dioxide, Carbon monoxide, Ozone, Phosgene, Hydrogen Fluoride, Carbon Dioxide.
Weld Fume Composition Ex.

Lead oxide  
Iron oxide  
Phosgene  
Ozone  
Carbon Monoxide  
Carbon Dioxide  
Nitrogen Oxide  
Formaldehyde  
Hydrocyanic acid  
Manganese  
Chromium IV  
Thorium dioxide  
Magnanese  
Beryllium oxide  
Nickel oxides

Weld Fume Composition

Paint  
Rust inhibitor  
Solvents  
Fluorides  
Silicates
What are welding fumes?

Produced when metals are heated above their melting point, vaporize, and condense into fumes.

Weld-fume particles come from consumable electrodes, molten puddles, shielding gases, base metals, or previously applied paint/surface coatings.

www.aws.org
Deposition of particles

Simulation of the Human Respiratory System

PRESEPARATOR
10 micrometers and above
STAGE 0
9.0 µm - 10.0 µm
STAGE 1
5.8 µm - 9.0 µm
STAGE 2
4.7 µm - 5.8 µm
STAGE 3
3.3 µm - 4.7 µm
STAGE 4
2.1 µm - 3.3 µm
STAGE 5
1.1 µm - 2.1 µm
STAGE 6
0.65 µm - 1.1 µm
STAGE 7
0.43 µm - 0.65 µm

- > 5 µm impaction
- 1-5 µm sedimentation
- < 1 µm like gas
Factors Affecting Exposure

- Type of welding process
- Base metal and filler metals used
- Welding rod composition
- Shielding gas ratio
- Use of ventilation controls
- Degree of enclosure
- Air movement
- Current and voltage
Factors Affecting Exposure

• The work practices of a welder
  – Use of proper Personal Protective Equipment (PPE)
  – Position of the welder
  – Surface cleaning
  – Working upwind when welding outdoors
Welding Fume Exposure and Health Effects

- Fumes
- Gases
- Vapours
Welding exposure – Health Effects

• Acute effects
  – Eye, nose and throat irritation, dizziness and nausea

• Chronic Effects (welding fumes and UV radiation)
  – Cataracts
  – COPD, Occupational asthma, Pneumonia
  – Parkinson, Metal Fume fever
  – IARC classified as group 1 carcinogen
    • Type of cancer depends on material and type of process
      – Lung cancer, kidney cancer, eye melanoma
Medical Surveillance

• Surveillance for Cr/Ni/Cd/Be/Mn is not mandated (they are not designated substances) in Ontario and BC
• Spirometry and symptom assessment
• Blood and urine testing not recommended as results are difficult to interpret in individuals unless they are compared with BEIs
• Biological testing could be considered when checking control methods in a group of workers (e.g., to verify that control methods are working)
Medical Surveillance

• Checking for lung cancer can be difficult:
  – Chest x-ray
    • Pros: simple, inexpensive, little radiation
    • Cons: may miss cancers, ? frequency
  – CT scan
    • Pros: good at detecting early cancer
    • Cons: expensive, lots of radiation (50x CXR)
• The best approach depends on each person’s circumstance, e.g., other risk factors, risk tolerance
Biomonitoring

- Biomonitoring can be done for specific metals in the welding fumes which has a BEI.
- Commonly used biomedia are blood and urine.
- One has to consider the timing between exposure and sample.

It should be noted that the presence of a metal or its metabolite in the blood or urine only confirms the exposure.
Major metals and their health effects

- Chromium
- Manganese
- Nickel
- Iron
- Beryllium
Chromium exposure

• Chromium is naturally occurring in rocks, plants and soil
  – 3 main forms of chromium
    • Chromium(0)
    • Chromium(III)
    • Chromium(IV)

• How does it enter the body
  – Inhalation (main route)
  – Ingestion and skin (small amounts)
Chromium – Health Effects

- Irritation to respiratory tract
  - Runny nose, shortness of breath, coughing, wheezing (acute)
  - Nasal perforation and ulceration
  - Bronchitis, decreased pulmonary function (chronic)

- Asthma sensitizer (CrIII,CrVI)

- Lung cancer (CrVI)

- Skin sensitizer/allergy (CrIII,CrVI)
  - Rashes

- Animal studies: stomach irritation, anemia, stomach and intestinal tumours, sperm damage
Hexavalent Chromium in the Body

- Most Cr is either absorbed by the lung or Gastrointestinal tract, with some skin absorption
- Inside the cell Cr(VI) is reduced to Cr (III)
- Once absorbed, its excretion is usually rapid via urine (half-life = 15 to 41h) but certain exposures may lead to much longer duration
- 3 compartments: may have half-life of years
Biological Tests

- **Blood Analysis** ($30 plasma blood, NOT covered by OHIP)
  - Plasma, whole blood, erythrocytes
  - Can distinguish Cr(VI) vs. other forms of Cr by measuring red blood cells (erythrocytes) vs. plasma

- **Urine Analysis** ($60, not covered by OHIP)
  - Measures TOTAL Chromium (CrVI and CrIII)
  - Two ways of measuring:
    - End of shift at end of workweek
    - Before shift and at the end of shift (to check increase in total Cr)
What can affect chromium levels (blood and urine)

- Physical activity
- Dietary Supplements
- Foods
- Smoking
What is a normal Cr level?

- If you are occupationally exposed, you will likely have higher levels than what the lab reports: they give “normal” values for non-exposed populations.
- BEI for total Chromium is 0.7 µg/L (ACGIH 2022).
- Treatment of elevated Cr levels = TIME and possibly avoidance of exposure.
Should we test for Cr in the body?

- The best method is urine Cr (end of week, or change across shift)
- *Measuring chromium in our bodies does not tell us about potential health effects*
- Can be helpful to determine how much exposure/absorption someone has
  - e.g. Is the respirator effective? Are the control programs effective?
Manganese

Neurological and neurobehavioral deficits from low exposure include changes in mood and short-term memory, altered reaction time, and reduced hand-eye coordination.

Male workers also have a higher risk of fertility problems.

There is no BEI for manganese since the corelation between manganese airborne and urine concentration is weak.
Manganese

- Manganese is an essential nutrient.
- Inhaled manganese bypasses the metabolism and accumulates in the body.
- The accumulation causes damage to lungs, liver, kidney, and central nervous system.
- Chronic high exposure (>0.1 mg/m³ - TLV) may lead to parkinsonian syndrome or Manganism.
- Parkinson-like symptoms may include tremors, slowness of movement, muscle rigidity, and poor balance.
Nickel (Ni)- Health effects

- The adverse health effects depend on the solubility or bioavailability of the nickel compounds.
- The health effects from nickel exposure are mainly chronic irritation, inflammation, and cancer of the respiratory system and allergic contact dermatitis.
Nickel solubility

- Soluble Ni compounds are Ni salts such as chloride, carbonate, sulfate, carboxylate and hydroxide. These compounds are commonly used in the electroplating industries and the manufacture of Ni-cadmium batteries.
- Poorly soluble Ni compounds include oxides which is commonly found in Ni refineries and in welding fumes (Ni +2 and +3)
- Ni (sub)sulfides and Ni oxides can not be strictly categorized as soluble or poorly soluble.
Nickel fate in the body

- Inhalation
- Ingestion
- Skin absorption
- Distribution
- Elimination
Nickel - BEI

- Biological Exposure Indices (BEI) is the association between airborne exposure to nickel and its compounds and its excretion in the urine.
- BEI for elemental nickel and poorly soluble nickel is 5 µg/L (ACGIH 2022).
- BEI for soluble nickel compounds is 30 µg/L (ACGIH 2022).
- BEI is for a urine sample collected post shift at the end of work week.
Iron Oxides

The major contaminant in all iron or steel welding processes.

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.
Beryllium

Hardening agent found in copper, magnesium, aluminum alloys and electrical contacts.

"Metal Fume Fever." A carcinogen.

Other chronic effects include damage to the respiratory tract; respiratory sensitizer.
WELDING EXPOSURE PREVENTION STRATEGIES
PREVENTION PROGRAM

- Substitution
- Engineering controls
- PPE
- Medical Surveillance
Prevention

[Diagram showing the hierarchy of controls for hazardous substances, with levels from top to bottom:
1. Elimination/Substitution
2. Engineering Controls
3. Administrative & Work Practice Controls
4. Personal Protective Equipment (including respirators)]

https://www.osha.gov/SLTC/hazardoustoxicsubstances/control.html
Welding Fume Generation

**Flux Core Arc Welding (FCAW)** filler metal electrode; flux shield

**Shielded Metal Arc (SMAW)** electrode provides both flux and filler material

**Gas Metal Arc (GMAW or MIG)** widely used; consumable electrode for filler metal, external gas shield

**Tungsten Inert Gas (GTAW or TIG)** superior finish; non-consumable electrode; externally-supplied inert gas shield
## Exposure limits

<table>
<thead>
<tr>
<th></th>
<th>Hexavalent Chromium (mg/m³)</th>
<th>Manganese (mg/m³)</th>
<th>Nickel (mg/m³)</th>
<th>Iron (mg/m³)</th>
<th>Beryllium (mg/m³)</th>
<th>Welding fumes (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLTSD OEL</td>
<td>0.01</td>
<td>0.2</td>
<td>1 (I)</td>
<td>5 (R)</td>
<td>0.00005 (I)</td>
<td>-</td>
</tr>
<tr>
<td>ACGIH - TLV</td>
<td>0.0002 (I)</td>
<td>0.1 (I)</td>
<td>1.5 (I)</td>
<td>5 (R)</td>
<td>0.00005 (I)</td>
<td>5 (withdrawn)</td>
</tr>
<tr>
<td>OSHA - PEL</td>
<td>0.005</td>
<td>5</td>
<td>1</td>
<td>10 (fume)</td>
<td>0.002</td>
<td>-</td>
</tr>
<tr>
<td>NIOSH – REL</td>
<td>0.0002</td>
<td>1</td>
<td>0.015</td>
<td>5 (dust and fume)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>GESTIS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

I= Inhalable  
R= Respirable  

OHCOW recommended 0.1 mg/m³ as total welding fumes to protect against carcinogenic effect of welding fumes
Occupational Exposure Banding at a Glance

Occupational exposure banding is a tool that can provide guidance for making risk management decisions when an authoritative OEL is not available. Occupational exposure bands not only provide a range of air concentrations expected to protect worker health but also can be used to identify potential health effects and target organs, identify health risks that necessitate health communication, inform implementation of control interventions and preparedness plans, inform medical surveillance decisions, and provide critical chemical toxicity information quickly.

Occupational exposure banding uses easily accessible qualitative and quantitative hazard information on selected health effect endpoints to identify potential inhalation-based exposure ranges or categories for guiding occupational risk assessment and risk management. The occupational exposure banding process provides a series of concrete steps to guide users through the evaluation of health hazard information and identification of the appropriate occupational exposure band from among five categories based on the severity of health outcomes (bands A to E; band A is highest air concentrations, and band E is lowest air concentrations) (Figure 0-1).

![Occupational exposure bands](image)

**Figure 0-1.** Occupational exposure bands [McKernan et al. 2016].

**Note:** When OSHA and other regulatory bodies limit occupational exposure to chemical substances, users should defer to those regulations, rather than an estimated occupational exposure band. For example, Particulates Not Otherwise Regulated (PNOR) have OSHA exposure limits of 15 mg/m³ for total dust and 5 mg/m³ for respirable fraction [29 CFR 1910.1000 Table Z-1] [OSHA 2012].

The banding process uses a three-tier approach (Figure 0-2). Selection of the most appropriate tier for a specific banding situation depends on the quantity and quality of the available data and the training and expertise of the user.
Mechanical/general Ventilation

- Air forced into and out of work area
- Roof exhaust fans
- Wall fans

NOTE: Air volume should deflect fume out of welders breathing zone.

IHSA Tools and Techniques: Welding and Cutting chapter 41
Local Exhaust ventilation (LEV)

FILTAIR® Capture 5 208/230 V, 10 ft. Arm (millerwelds.com)

Welding fume extraction | Fume Eliminator 24/7 | Nederman

Welding and Grinding table (nederman.com)

Fume Extraction for CNC Plasma Cutting machines (cityplasma.co.uk)
Correct use of LEV

• Distance from the arc
• Capture velocity
• Design of the exhaust hood
• Level of enclosure
• Equipment maintenance
• Training
Personal Protective Equipment

[Image of various personal protective equipment items]

[Image of a PAPR with T94-R™ (millerwelds.com)]

Personal Protective Equipment

Powered Air Purifying respirators and N95 (provided proper fit) can be very effective in reducing the welding fume exposure, however, they can be difficult to use in confined spaces.

![Graph showing respirable welding fume levels with and without PAPR](image)
Personal Protective Equipment

Recent studies have shown only marginal reduction of welding fumes from welding helmet and the reduction factors varied due to different factors such as level of exposure, position of the welder, type of welding etc.
Respitory Protection Program

Selection, use, and care of respirators
# Assigned Protection Factor (APF)

<table>
<thead>
<tr>
<th>Respiratory mask</th>
<th>APF</th>
<th>Fit testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half mask/Dust mask</td>
<td>10</td>
<td>Needed</td>
</tr>
<tr>
<td>Half mask (elastomeric)</td>
<td>10</td>
<td>Needed</td>
</tr>
<tr>
<td>Full facepiece (Elastomeric)</td>
<td>50</td>
<td>Needed</td>
</tr>
<tr>
<td>Loose-fitting Powered Air-Purifying Respirator (PAPR)</td>
<td>25</td>
<td>Not needed</td>
</tr>
<tr>
<td>Hood Powered Air-Purifying Respirator (PAPR)</td>
<td>25</td>
<td>Not needed</td>
</tr>
<tr>
<td>Full Facepiece Supplied-Air Respirator (SAR)</td>
<td>1000</td>
<td>Needed</td>
</tr>
<tr>
<td></td>
<td>10,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>if used in escape mode</td>
<td></td>
</tr>
<tr>
<td>Full Facepiece Abrasive Blasting Continuous flow</td>
<td>1000</td>
<td>Needed</td>
</tr>
<tr>
<td>Full Facepiece Self-Contained Breathing Apparatus (SCBA)</td>
<td>10,000</td>
<td>Needed</td>
</tr>
</tbody>
</table>

OSHA APF 2009
Assigned Protection Factor (APF)

Required APF = \( \frac{\text{Exposure concentration}}{\text{Occupational Exposure Limit}} \)

Maximum Exposure Limit = \( \text{Exposure Limit} \times \text{APF} \)

= 0.01 \times 10 = 0.1
OSHA respiratory selection eTool

Respiratory Protection eTool

Respirator Change Schedules

Respirator Selection

The OSHA respirator standard applies to all occupational airborne exposures to contaminated air where the employee is:

- Exposed to a hazardous level of an airborne contaminant; or
- Required by the employer to wear respirators; or
- Permitted to wear respirators.

Four major duties are imposed by each of these standards. These duties are:

- Use engineering controls where feasible to control the hazard.
- Provide an appropriate respirator.
- Ensure the use of an appropriate respirator.
- Institute a respiratory protection program that complies with the rest of the standard.

Applicable OSHA Standards:

- 29 CFR 1910 Subpart I, Personal protective equipment. OSHA Standard:
  - 1510.134. Respiratory protection
  - 1910.134(a). Permissible practice

Keep In Mind

The display of use of particular products in this advisor is for illustrative purposes only and does not constitute an endorsement by the U.S. Department of Labor.
Welcome to the Breathe Freely Welding Fume Control Selector Tool
Thank You

Questions?

Masood Ahmed mahmed@ohcow.on.ca
OH-PODS: Occupational Health Podcasts

This is a podcast series by the Occupational Health Clinics for Ontario Workers (OHCOW), where we discuss the challenges of current and emerging trends in occupational health and offer effective prevention strategies to empower workers.

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https://www.ohcow.on.ca/OH-PODS-Podcasts.html