Principles of Industrial Hygiene

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The findings and conclusions in this presentation are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.
Agenda

- NIOSH/Western States Office
- Industrial Hygiene
  - Environmental Factors and Stressors
  - Hexavalent Chromium
  - Noise
  - Toxicology and Risk
  - Occupational Exposure Limits
  - Developing an Exposure Assessment Strategy
  - Hierarchy of Control
  - Personal Protective Equipment
  - Respiratory Protection
Occupational Safety and Health Act of 1970

To assure safe and healthful working conditions for working men and women.
NIOSH

Joined CDC in 1973
NIOSH Locations

NIOSH Staff: ~1,200

Washington, DC
Atlanta, GA
Cincinnati, OH
Morgantown, WV
Pittsburgh, PA
Spokane, WA
Anchorage, AK
Denver, CO
NIOSH Functions

- Epidemiology
- Field Studies
- Lab studies
- Exposure measurement
- Control Technology
- Protective Equipment
- Training
- Information Dissemination
WSO Initiatives/Functions

• Promote and support sustainable state-based occupational injury and illness surveillance

• Define and address health issues in the Oil and Gas extraction industry

• Provide Western support for NIOSH programs and activities
  – Fatality Investigations
  – Construction Safety and Health
  – Health Hazard Evaluations
  – Uranium Fuel Cycle Worker Safety and Health
  – Wildland Fire Fighter Safety and Health
  – Health Communications

• Collaborate with Western stakeholders
Industrial Hygiene

• “that science and art devoted to the anticipation, recognition, evaluation, and control* of those environmental factors or stresses, arising in or from the workplace, that may cause sickness, impaired health and well-being, or significant discomfort and inefficiency among workers”

* Ensure you “Confirm”!
Environmental Factors or Stresses

• Chemical hazards
  – gases, vapors, dusts, fumes, mists, and smoke

• Physical hazards
  – non-ionizing and ionizing radiation, noise, vibration, extreme temperatures and pressures
Environmental Factors or Stresses

• Ergonomic hazards
  – workstation design, repetitive motion, improper lifting/reaching, poor visual conditions

• Biological hazards
  – insects, mold, yeast, fungi, bacteria, and viruses
Potential Industrial Hygiene Issues

- Noise
- Ergonomics
- Chloramines
- Organic Dust
- Heat Stress
- Cr(VI)

- Ammonia
- Sanitizers
- Infectious Agents (Brucellosis, Avian Influenza)
- Feed Additives
- Hydrogen Sulfide
- VOC’s
Hexavalent Chromium

Hexavalent chromium (Cr(VI)) compounds are a group of chemical substances that contain the metallic element chromium in its positive-6 valence (hexavalent) state.

Occupational exposures to Cr(VI) occur during the production of stainless steel, chromate chemicals, and chromate pigments. Cr(VI) exposures also occur during other work activities such as stainless steel welding, thermal cutting, and chrome plating.
Hexavalent Chromium

- OSHA Comprehensive Standard (29 CFR 1910.1026),
  - 5 µg/m³ PEL, 2.5 µg/m³ Action Level
  - Requirements for exposure determination, regulated areas, respiratory protection/PPE, medical surveillance, hygiene practices, housekeeping, hazard communication, recordkeeping

- Does not apply to:
  - Pesticide application
  - Portland Cement
  - objective data demonstrating that Cr(VI) concentrations cannot exceed 0.5 µg/m³ as an 8-hour time-weighted average under any expected conditions of use.
Full Shift REL (analogous to Cr(VI))

Exposure at the NIOSH Silica REL of 0.05 mg/m³ and assuming the worker breathed 10 m³
Hexavalent Chromium

Cr(VI) can be formed when performing “hot work” such as welding on stainless steel, melting chromium metal, or heating refractory bricks in kilns. In these situations the chromium is not originally hexavalent, but the high temperatures involved in the process result in oxidation that converts the chromium to a hexavalent state.
Hexavalent Chromium

- NIOSH considers all Cr(VI) compounds to be potential occupational carcinogens. Occupational exposure to Cr(VI) compounds is associated with lung, nasal, and sinus cancer. Other respiratory effects include nasal irritation and ulceration, and perforation of the nasal septum and eardrum. Dermal exposure to Cr(VI) compounds can cause skin irritation, ulceration, sensitization, and allergic contact dermatitis.
Quantitative Risk Assessment
  - Chromate workers

Proposed REL: 0.2 µg/m$^3$
  - All Cr(VI) compounds
  - Reduce risk for lung cancer over a working lifetime
  - Excess risk of lung cancer death at proposed REL is ~1/1000

Dermal Exposure
  - Irritation
  - Allergic Contact Dermatitis
  - Sensitization
Noise as an Occupational Health Problem

- Hearing Loss is pervasive and insidious
  - NIHL is cumulative and permanent

- 1.7 million workers between 50-59 have compensable NIHL

- 14% of workforce are employed in jobs where the noise level exceeds 90 dBA
Deleterious Effects of Chemical Exposure

- Whether or not an adverse effect from a chemical occurs is dependent on:
  - The chemical and physical properties of the agent
  - The exposure situation
    - Duration and Frequency of Exposure
    - Route of Exposure
    - Concentration of Contaminant
    - Acute vs Chronic
  - The susceptibility of the biological system
Routes of Entry

• Inhalation
  – airborne contaminants

• Absorption
  – penetration through the skin

• Ingestion
  – eating
  – drinking
Particle Size Conventions

- Respirable: 50% cutpoint = 4 µm
- Thoracic: 50% cutpoint = 10 µm
- Inhalable: 50% cutpoint = 100 µm
Hazard, Toxicity, Dose, Risk, Safety

- **Toxicity**: The capacity of a substance to produce injury
- **Dose**: The quantity of a substance to which an organism is exposed
- **Hazard**: The likelihood that injury will result under specific conditions - a condition that poses a threat of loss
  - e.g., Toxicity of a substance X probability of exposure
- **Risk**: The combined probability and severity of loss
  - Has magnitude and probability
- **Safety**: The probability that harm will not occur under specified conditions
  - Not an absolute, but judgmental
  - A thing is safe only to the degree that its risks are acceptable
Why is Exposure Assessment Important?

- Determine the magnitude and significance of health hazards
- Evaluate the need, type, and effectiveness of controls
- Regulatory requirements
- Worker anxiety/Complaint investigation
- Epidemiology/Surveillance/Research
- Hazard Communication/Training
Exposure Assessment’s Central Role in OH&S Program Management
Developing an Exposure Assessment Strategy

- Why/Who
- How/How Often
- When
- How Long
- How Many
- Air
- Bulk
- Surface
Always know how you are going to interpret the results and manage the data before you sample. Our ability to measure FAR EXCEEDS our ability to understand results.

In almost all cases, you have to know what you are looking for and the potential interferences before you can sample.
Data Interpretation and Reporting

What have we learned?

How do we explain it?

What does a “positive” result mean?

What does a “non-detect” result mean?

What does an “indeterminate” result mean?
Control Hierarchy*

1. Elimination
2. Alteration
3. Substitution
4. Isolation
5. Engineering
6. Reduction in exposure time
7. Personal protective equipment

*The philosophy of minimizing exposure using the most effective and true solutions first.
PPE Selection

• Determine the hazards most likely to occur
• Assess adverse effects of unprotected exposure
• Identify other control options that can be used instead of protective clothing
• Determining the performance characteristics needed for protection
• Evaluating the need for decontamination
• Assess constraints that may hinder the use of PPE (ergonomics, safety, vision, dexterity)
Respiratory Protection

• Respiratory hazards
• Respiratory protection basics
  – Types, APF
• Respirator selection
• Programmatic requirements
  • Responsibilities
  • Medical clearance
  • Fit testing
  • Maintenance and storage
  • Recordkeeping
Respirator Selection

• Essential for proper protection!

• Must consider:
  – Type and concentration of contaminant
  – Use environment
  – Appropriateness of filters/cartridges
  – Other PPE needs (e.g., eye protection)

• Tools for respirator selection:
  – Maximum Use Concentration (MUC) calculation (APF x OEL)
  – NIOSH Respirator Decision Logic
Thank you for your Attention

Questions/Discussion?

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www.cdc.gov/NIOSH
When to Monitor

- Full-Shift
- Across Shifts
- Seasonal Considerations
- Activity-Specific
Air Sampling

• Units: Mg/m$^3$, ppm, f/cc

• Calibration – primary and secondary
  – Pre and Post Calibration (temp and pressure)
  – Rotameters
  – Critical Orifice
  – Bubble Buret

• Making known concentrations
Integrated Sampling

• Gases and Vapors
  – Mixtures
  – Active and Passive Monitoring
  – Sorbent tubes
  – Impingers
• Aerosols
  – Filter
  – Cyclones/Impactors
Sorbent Tube Sampling Train
Sorbent Tube

- Sealing Caps prevent contamination.
- High-Purity Glass Wool precisely measures amount for uniform pressure drop.
- Precision Lockspring holds sorbent layers securely in place to prevent sample channeling, allowing transporting without damaging sample (patented).
- Glass Tube drawn to very close tolerances for repeatable results.
- Sorbent Layer precisely controlled surface area, pore size, adsorptive characteristics, particle size.
- Backup Sorbent Layer detects sample breakthrough.
- Foam Separator for uniform pressure drop.
- Precision-Sealed Tips permit safe, easy breaking to the specified opening size.
Diffusive Monitor – Passive
Analysis

- Gas Chromatography (FID, EC, etc)
- GC/MS
- AA, ICAP - AES
- HPLC
- IC
Analytical Considerations

- Laboratory Accreditation
- Sampling and Analytical Error
  Combined effect of errors inherent in sampling, analysis, and pump flow.
  Environmental variables far exceed SAE
- Confidence Limits (LCL, UCL)
Analytical Parameters

Stability

Collection Efficiency

Desorption Efficiency

Temperature and Pressure Corrections
Complacency

Continued vigilance is critical – particularly when dealing with rare events

Burdensome requirements without clearly understood benefits are difficult to sustain

“Culture” change is often necessary
Even Engineers have a bias toward belief that events occur toward the end of probability periods (e.g. once every 50 years)
PPE Requirements

Properly Selected PPE Should:

- Provide adequate protection against the particular hazards for which they are designed.
- Be of safe design and construction for the work to be performed.
- Be reasonably comfortable.
- Fit snugly and shall not unduly interfere with the movements of the wearer.
- Be durable.
- Be capable of being disinfected.
- Be easily cleanable.
- Be distinctly marked.
Selecting PPE for the Workplace

Regulatory (OSHA) Requirements

Conduct a Hazard Assessment to determine if the use of respiratory, eye and face protection is necessary

A hazard assessment determines the risk of exposure to respiratory, eye and face hazards, including emergency situations.

- 1910.134
- 1910.132(a)
- 1915.153(a)(1)
- 1910.133(a)(1)
- 1926.153(a)(1)
Types of Air Contaminants

• **Fibers**
  – elongated structures with a high aspect ratio

• **Gases**
  – formless fluids that expand to occupy a space

• **Vapors**
  – volatile form of substances that are normally in a solid or liquid state at STP

• **Fogs**
  – Droplet aerosols that are a product of condensation
Types of Air Contaminants

• Fumes
  – Condensation of a volatilized solids
    • < 1.0 μm in diameter
    • In most cases, the solid particles resulting from the condensation react with air to form an oxide

• Mists
  – finely divided liquid suspended in the atmosphere

• Smokes
  – Complex mixtures of solid and liquid aerosols, gases and vapors
    • Result of incomplete combustion
Types of Air Contaminants

• Aerosols – broad term
  – Solid or liquid particles dispersed in a gaseous medium
  – dusts, fumes, mists, fibers, bioaerosols
  – respirable and non respirable particles
    • > 10 μm in diameter
  – respirable particles
    • < 10 μm in diameter
Occupational Exposure Limits

TLV-TWA: The time-weighted average airborne concentration to which it is believed nearly all workers may be exposed day after day without adverse health effects
Occupational Exposure Limits

BEI – Biological Exposure Indices are guidance values for assessing biological monitoring results. BEIs represent levels most likely to be observed in workers exposed to chemicals to the same extent as inhalation exposure to the TLV.
How Long to Sample

• Full-Shift - TWA
• STEL
• Instantaneous Monitoring
• Task-Specific
• Analytical Considerations (volume)
Analytical Methods

- NIOSH Methodology
- OSHA FOM
- APHA
- ACGIH - References
- ASTM – Validation
- TALK TO THE LAB!
Who Do You Monitor?

• Exposure monitoring is not always essential to the evaluation
• Modeling can be used
  – Monitor if > 10% of OEL
• Similar Exposure Groups
• Statistical Considerations
• Control Banding
Hierarchy of Controls

The philosophy of minimizing exposure using the most effective and true solutions first.
Welding Exposure – Power Plants

The most common welding process conducted on chromium bearing metals at power plants, is shielded metal arc welding (SMAW). This type of welding can give rise to airborne Cr(VI) concentrations in excess of the OSHA permissible exposure limit (PEL), especially when consumables contain more than 3% chromium (Cr).
Arc gouging consistently showed the highest Cr(VI) exposures, even when LEV is used. Gas-tungsten arc welding (GTAW) is the second most common type of welding process used at electric utilities. None of the air samples collected during this welding process exceeded the PEL,
Monitoring Considerations

- Analytical Methods
- Laboratory Coordination
- Sample Preparation
- Calibration
- Blanks
- Interferences
- Personal vs Area Air Samples
Analytical Considerations

Choice of Method
Accuracy and Precision
Sensitivity
  LOD and LOQ
Temperature and Humidity
Breakthrough
Flow Rate
Interferences
Direct Reading Instrumentation

- Colorimetric Tubes
- Photo-ionization Detectors
- Electrochemical Cells
- Other (GC, IR, Photoacoustic)
- Grab Sampling
GC/MS Analysis
SEQ 9666
THERMAL DESORPTION TUBES
PEAK IDENTIFICATION

1) Air*/CO₂*
2) Dichlorodifluoromethane*
3) Methanol*/isobutane
4) Butane*
5) Ethanol
5A) Acetone
6) Isopentane*
7) Isopropanol
8) Pentane*
9) C₅H₈ isomer (isoprene)
10) Isobutyraldehyde?
11) C₆ aliphatic hydrocarbons
12) Methyl ethyl ketone (MEK)
13) Hexane
13A) Ethyl acetate
14) Tetrahydrofuran
15) Methyl cyclopentane
16) 1,1,1-Trichloroethane
17) Methyl isopropyl ketone
18) Benzene*/butanol
19) Cyclohexane
20) Ethylene glycol
21) Pentanal*
22) C₇ aliphatic hydrocarbons
23) Methyl methacrylate (MMA)
24) Propyl acetate
25) Heptane
26) Propylene glycol
27) Methyl cyclohexane/methyl isobutyl ketone (MIBK)
28) C₈ aliphatic hydrocarbons
29) Hexanol
30) Toluene
31) Cyclopentanone
32) Hexanal*
33) Butyl acetate
34) Octane
35) Hexamethyldisiloxane*
36) Propylene glycol methyl ether acetate
37) Xylene/ethyl benzene isomers
38) Styrene
39) Butyl cellosolve
40) C₉-C₁₆ aliphatic hydrocarbons including alkyl cyclohexanes, alkyl decahydronaphthalenes, plus some C₅-C₁₀ alkyl benzenes
41) Nonane
42) C₈-C₁₀ aliphatic aldehydes*
43) Octamethylcyclotetrasiloxane*
44) Decane
45) Dichlorobenzene isomer(o- or m-)
45A) Limonene
46) Undecane
47) Decamethyldicyclopentasiloxane*
48A) Naphthalene
48) Dodecane
49) Tridecane
50) Methyl naphthalenes
51) Siloxane compound*
52) C₁₂H₂₄O₂, methyl propanoic acid esters such as:
   a) 2,2-dimethyl-1-(2-hydroxy-1-methylethyl)propyl ester
   b) 3-hydroxy-2,4,4-trimethylpentyl ester
53) Tetradecane
54) Diisopropyl adipate
55) Dimethyl phthalate*
56) Methyl ionone, C₁₄H₁₆O isomer?
57) Pentadecane
58) Diethyl phthalate*
59) Hexadecane

*Also present on some media and/or field blanks.
Fixed Monitoring Devices

• Purpose of Continuous Monitoring
  – Emergency Notification
  – Surveillance and record keeping

• Types of Continuous Monitors
  – Sample collection and transport
  – Direct Reading

• Calibration and Annunciation
Principles of Personal Protective Equipment

• Personal protective equipment (PPE) is generally considered the last line of defense, efforts to eliminate the hazard through engineering or administrative controls should be implemented first.

• PPE places the burden of protection on the employee, and if the equipment fails, exposure could occur.
SAFETY FIRST

Please NO
Perfumes or Lotions

Perfumes & Lotions make Gwen, Cindy, Pat & Sue unable to breath
Units of Concentration

• ppm
  – parts per million (v/v)
• mg/m$^3$
  – milligrams per cubic meter (m/v)
• mppcf
  – millions or a particle per cubic foot
• f/cc
  – fibers per cubic centimeter
Occupational Exposure Limits

- Threshold Limit Values (ACGIH)
- Biological Exposure Indices (ACGIH)
- Permissible Exposure Limits (OSHA)
- Recommended Exposure Limits (NIOSH)
- Others (WEEL, AEGL, MAC)
- Time Weighted Average
- Short-Term Exposure Limit
- Ceiling Limit
- IDLH
- Skin Notations
Types of Air Contaminants

- Gases
- Vapors
- Fumes
- Fibers

- Fogs
- Mists
- Smoke
- Other Aerosols
Other Classifications

**Physical Properties**
- Corrosive
- Toxic/Poisonous
- Oxidizer
- Flammable
- Reactive
- Explosive

**Physiological Effects**
- Irritants
- Asphyxiants
  - mechanical and chemical
- Anesthetics
- Sensitizers
- Carcinogens/Mutagens
- Systemic Poisons/Target Organs
- Infectious
Types of Respirators

• Air purifying:
  – Filter or chemical cartridge removes contaminants
    • Filtering Facepiece
    • Elastomeric (half- and full-face)
    • PAPR

• Atmosphere supplying:
  – Provides a clean source of breathing air from a self contained or remote source
    • Airline/SCBA/Closed Circuit/Escape
Air purifying respirators

- Inhaled air passes through filters or cartridges.

  **Filters:**
  - Entrap solid particles or liquid droplets on a fibrous filter
  - Particles collected by various filtration mechanisms

  **Cartridges:**
  - Adsorb gases or vapors in a sorbent bed
  - Susceptible to breakthrough
Filtration mechanisms

Inertial impaction

Interception

Diffusion

Electrostatic attraction
P-100 filter
P-100 filter media
Filters – how they work

- Fibers, not mesh
- Particles pass through a “web”
- When particles touch a fiber, they adhere
- Inertia carries larger particles onto fibers
- Smaller particles diffuse onto fibers
- MPPS ~ 0.3 µm
Filters

• Classified by series and level of filtration

• Series:
  – N series is not for use with oil aerosols.
  – R series is resistant to oil aerosols (good for a single shift).
  – P series is “oil proof” (good for multiple shifts).

• Level of filtration:
  – 95 level has minimum efficiency of 95%
  – 99 level has minimum efficiency of 99%
  – 100 level has minimum efficiency of 99.97%

• Examples: N95, R99, P100
  – These refer to a filter class, not a respirator
Cartridges

• Cartridges are specific to a contaminant or class of contaminants

• Color coded according to contaminant.

• In mixed environments:
  – May use particulate filters *before* cartridges.
  – May use different cartridges in series.

• May have end of service life indicator (ESLI).
Atmosphere supplying respirators

- Provide safe breathing air from a remote or self contained source
- Air supplies may include:
  - Cylinders of compressed air
    - Self contained or airline
  - Ambient air pumped from a remote location
  - Oxygen generated by chemical reaction

**WSO Personnel are not permitted to enter environments requiring atmosphere supplying respirators**
Operating modes

• Negative pressure:
  – Inhalation draws ambient air through filters and/or cartridges
  – Used with tight-fitting face pieces

• Continuous flow:
  – Air is supplied at a constant rate
  – Used with powered air purifying respirators (PAPRs), escape respirators, and loose fitting supplied air respirators

• Pressure-demand:
  – Air is supplied when pressure in face piece drops below a set point
  – Used with self-contained breathing apparatus (SCBA) and airline respirators
Protection Factor Terminology

- **Protection Factor:** The ratio of outside contaminant concentration to inside concentration
- **Assigned Protection Factor (APF):** The minimum anticipated protection provided by a properly functioning respirator or class of respirators to a given percentage of properly fitted and trained users.
- **Fit Factor:** A quantitative measure of the fit of a specific respirator facepiece to a particular individual
- **Workplace Protection Factor (WPF):** A measure of the protection provided in the workplace by a properly functioning respirator when correctly worn and used
### Assigned Protection Factors

<table>
<thead>
<tr>
<th>Type of respirator</th>
<th>Quarter mask</th>
<th>Half mask</th>
<th>Full facepiece</th>
<th>Helmet/hood</th>
<th>Loose-fitting facepiece</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Air-Purifying Respirator</td>
<td>5</td>
<td>10</td>
<td>50</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2. Powered Air-Purifying Respirator (PAPR)</td>
<td>—</td>
<td>50</td>
<td>1,000</td>
<td>25/1,000</td>
<td>25</td>
</tr>
<tr>
<td>3. Supplied-Air Respirator (SAR) or Airline Respirator</td>
<td>—</td>
<td>—</td>
<td>10</td>
<td>50</td>
<td>—</td>
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<tr>
<td>• Demand mode</td>
<td>—</td>
<td>50</td>
<td>1,000</td>
<td>25/1,000</td>
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<tr>
<td>• Continuous flow mode</td>
<td>—</td>
<td>50</td>
<td>1,000</td>
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<tr>
<td>• Pressure-demand or other positive-pressure mode</td>
<td>—</td>
<td>50</td>
<td>1,000</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>4. Self-Contained Breathing Apparatus (SCBA)</td>
<td>—</td>
<td>—</td>
<td>10,000</td>
<td>10,000</td>
<td>—</td>
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<td>• Demand mode</td>
<td>—</td>
<td>—</td>
<td>10</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>• Pressure-demand or other positive-pressure mode (e.g., open/closed circuit)</td>
<td>—</td>
<td>—</td>
<td>10,000</td>
<td>10,000</td>
<td>—</td>
</tr>
</tbody>
</table>
Maximum Use Concentration (MUC)

- Used to identify appropriate classes of respirators for a given exposure situation.

- Determined by the lesser of:
  - APF * exposure limit (PEL, REL, STEL or C)
  - Manufacturer’s assigned MUC (for cartridges)

- IDLH value is a limiter
MUC examples

- If using a half face negative pressure respirator for acetone (REL is 250 ppm):
  - APF for half face negative pressure is 10.
  - $10 \times 250 \text{ ppm} = 2500 \text{ ppm}$

- Find the minimum acceptable respirator for a 5 ppm benzene exposure (REL is 0.1 ppm):
  - $5 \text{ ppm}/0.1 \text{ ppm} = 50 \text{ APF}$
  - Minimum is a full face negative pressure respirator (APF = 50).
Types of respirators used at WSO

• Filtering face piece

• Half-face reusable air purifying

• Full-face air purifying

• Full-face powered air purifying (PAPR)
Particulate Filtering Facepiece Respirators

• Filter out airborne particles
• Protection factor = 10
• Not adequate for:
  – Chemical gases or vapors
  – Asbestos
  – Dust levels > 10X PEL
  – Oxygen deficiency (confined work space)
• Cannot be cleaned, repaired
Respiratory Protection