Chemical Safety and Security Officer Training

Bangkok, Thailand
October 2010

Principles and Concepts of Laboratory Design

Purpose of Laboratory Design

- Protect the Workers
- Enable the Work
- Secure the Facility
- Protect the Environment
- Comply with Regulations

Objectives of Laboratory Design

- Provide a safe/secure workplace
- Facilitate workplace activities
- Efficient
- Cost Effective

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration.
Barriers to Good Lab Design

- Cost
- Poor Communication
- Lack of Scientific Knowledge
- Complicated Project
- Trade-offs
- Personalities
- Maintenance

Good Laboratory Design

Based on:

- Containment
  - Maximize Containment
  - Minimize Contamination
- Redundancy is the Key

Chemical Containment Concept

Chemical Protection Depends on:

1. Chemistry Knowledge
   - Workers must have knowledge and understanding
2. Containment
   - Safe/Secure Storage
   - Proper Work Practices
   - Good Engineering Controls
Chemical Protection Depends on, cont'd:

3
Construction
How well the facility is built

Key Stakeholders

Architects
Engineers
Administrators
Builders
EHS Professionals
Laboratory Users

Laboratory Design is an Iterative Process

Design Phases

Definition
(problems and needs)

Interpretation
(arrow)
(iterative process)

Design
(translates specifications into pragmatic reality)

Construction
(to accomplish goal)
Major US Standards & Guidelines

- ANSI Z9.5 American National Standards Institute, Z 9.5 Laboratory Ventilation Standard
- NFPA National Fire Protection Association
- BOCA Building Officials Code Association
- ASHRAE 110 American Society of Heating, Refrigeration and Air Conditioning Engineers, Standard 110 for Testing and Evaluating Laboratory Hoods
- Others
  - National Electrical Code
  - American Chemical Society, Green Chemistry Institute
  - www.acs.org/greenchemistry

Architectural Features Include:

- Layout of buildings and laboratories
- Space requirements
- Spatial arrangement of equipment and benches
- Emergency egress
- Storage requirements
- Waste requirements
- Access controls
- Security features

Lab Design Components

• Spatial
  - Floor plan
  - Location of rooms and equipment
  - Traffic flow of people and equipment
  - Access control

• Mechanical
  - Ventilation
  - Utilities
  - Effluent control
  - Control and monitoring

• Safety and Security

Factors in Laboratory Design

• Architectural
• HVAC*
• Safety and Security
  - Fire
  - Emergencies
  - Exposures
  - Access/exit control (facility, chemicals, equipment)

(* heating, ventilation, and air conditioning)
General Information Needed

- Number of occupants and their technical qualifications
- Space and storage requirements
- Utilities needed
- Equipment needs
- Time/duration of occupancy
- Anticipated changes in research/programs
- Sustainability (environmental, green initiatives)
- Security needs

Safety/Security Information Needed Before Design can Begin

<table>
<thead>
<tr>
<th>Type of Work/Research</th>
<th>Type of Hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>Biohazard</td>
</tr>
<tr>
<td>Biological</td>
<td>Radiation</td>
</tr>
<tr>
<td>High Voltage</td>
<td></td>
</tr>
</tbody>
</table>

Types of Chemicals (based on physical state and properties)
- Flammable
- Corrosive (acid or base)
- Reactive
- Acutely Toxic (poisons)
- Regulated
- Chronically Toxic (e.g., carcinogens, repro-toxins)
- Chemicals of security concern
- Controlled Drugs
- Wastes

Specific Chemical Laboratory Safety/Security Concerns

Include:
- Fire detection, alarms, and suppression systems
- Safety equipment (i.e. emergency showers, eyewash and contaminant control)
- Ventilation (i.e. laboratory hoods, glove boxes, ventilated enclosures)
- Management of chemicals and waste
- Access controls for facility and laboratories
Examples of Lab Design Considerations

• Sample preparation and storage area
• Segregate sample digestion using acid-specialized laboratory hoods
• Segregate solvent extraction to reduce vapor contamination
• Proper eyewash placement
• Adequate egress
• Waste storage area
• Gas bottle storage

Building Layout: Divide into Zones

• Zones or control areas may have different:
  - Types and degree of hazards
  - Amounts of hazardous chemicals
• Allows better control over:
  - Personnel access
  - Hazards using
    - Equipment
    - PPE
    - Administrative procedures
• Examples: Fire safety zones, HVAC zones, Building floors

Building Layout: Corridors

• Best practice is to separate movement of:
  - General population
  - Laboratory personnel
  - Chemicals and laboratory materials.
• Internal “service corridors” between labs
  - Allow transport of chemicals away from public
  - Provide access to utilities and other support equipment
  - Provide additional lab exits with emergency doors to main corridors

Building Layout: Entrance/Exit Doors

• Good safety: two or more exits from each lab/room/building
• Good security: control who can enter a lab/room/building
• Emergency exit doors:
  - Lack handles or are locked on outside
  - Have “panic bar” on inside
  - May set off alarm when opened
Building Layout: Chemical Stockrooms

- Multiple, specialized stockrooms rather than one central storeroom
  - Chemicals dispensed across counter
  - Access restricted to stockroom personnel
  - Locked when unattended

- Teaching stockroom
  - High traffic
  - Only keep ~1 week supply of chemicals needed for student experiments

- Central Stockroom
  - Wide variety of chemicals and materials
  - Additional controls and containment for regulated, attractive, or dual-use chemicals
  - Chemicals stored in compatible groups

Building Layout: Compressed Gases

- Install tanks outside building and pipe into lab
  - Long-term, frequent use of same gas
  - Highly hazardous gases
  - Restrict access
  - Out-building or outdoors, depending on conditions

- Tanks inside labs
  - Wide variety of gases
  - Low use rates
  - Strap to wall or bench
  - Transport safely

Building Layout: Chemical Waste

- Large volumes of chemical waste should be stored in areas with fewer people
  - Access restricted to responsible personnel
  - Locked when unattended
  - Divided into chemically compatible groups
  - Provide safety equipment and alarms
Building Layout: Chemical Waste

- Waste collection area in teaching/research labs:
  - Convenient student use
  - Empty/moved frequently
  - Divided into chemically compatible groups
  - Provide safety equipment

Modular Laboratory Design

- Uses standard size and layout of benches, equipment and utility connections
- Customize layout for specific applications
- Allows for:
  - Cheaper lab design
  - Easier lab modifications
  - Easier lab renovations

Current Trends in Laboratory Design of Safety/Security Concern

- Open Laboratories
- Energy Conservation
- Ventilation Concerns
- Hood Designs
- Hood Manifold systems
- Effluent Modeling from Exhaust Stacks
- Lab Decommissioning

Open vs. Closed Laboratories

Open Laboratory

Closed Laboratory
Open vs. Closed Laboratories

Consider using both or having connected access:

Open laboratories
- Support team work
- Facilitates communication
- Shared:
  - Equipment
  - Bench space
  - Support staff
- Adaptable and flexible
- Easier to monitor
- Cheaper to design, build and operate
- The trend since mid 90's

Closed laboratories
- Specialized, dedicated work
- More expensive
- Less flexible
- Easier to control access
- Needed for specific work
  - NMR
  - Mass spec
  - High hazard materials
  - Dark rooms
  - Lasers

Energy Conservation, Sustainability and Green Chemistry Concerns

- Design leading to increased productivity
- Energy conservation and efficiency
- Centralized heat-generating equipment
- Manifolded hoods and ventilation
- Reduction/elimination of harmful substances and waste
- Efficient use of materials and resources
- Recycling and reuse

Energy Conservation Issues

- Vented Enclosures
- Ductless Hoods
- Diversity
- Manifolded Systems
- Recirculation of Room Exhaust Air
- Variable Air Volume Systems
- Automatic Sash Closers
- Air Change per Hour
- Low Flow Hoods

Ventilation Considerations Include

- Heating and cooling needs
- Maintaining directional airflow
- Type of hoods
- Single vs. manifolded hoods
Laboratory hood design and ventilation are discussed in detail in later presentations.

**General Laboratory Hood Considerations**

- Determine minimum exhaust requirements.
- Communicate hood limitations to users.
- Label restrictions e.g., no perchloric acid.
- Alarm systems
- Consider future needs.

**Hood Manifold Considerations**

**Single Hood - Single Fan**

- 0.5 m³/s

**Manifold: 3 Hoods, 1 Fan**

- 1.5 m³/s
**Hood Manifold Considerations**

Hood Diversity = 33%

- Avoid re-entrainment
- Disperse emissions straight upward and downwind!

**Ventilation Design: Avoid Exhaust Recirculation**

- Try to locate hoods, utilities and safety equipment in the same relative position in all labs.
- Locate sinks centrally
- Space between benches should allow people to pass each other (≥1.5 m).
- Details on these topics given in later presentations:
  - Lab hoods
  - Safety showers / eyewashes
  - Chemical management

**Lab Layout**

- Try to locate hoods, utilities and safety equipment in the same relative position in all labs.
- Locate sinks centrally
- Space between benches should allow people to pass each other (≥1.5 m).
- Details on these topics given in later presentations:
  - Lab hoods
  - Safety showers / eyewashes
  - Chemical management
Teaching Lab Layout

• Higher occupancy than research labs
  – Need easy movement of people around lab
  – Two safe exits
  – Benches in “Islands”
  – 2m distance between benches so students can work “back-to-back”
  – Locate instruments, sinks, supply areas away from hoods to minimize traffic in front of them

• Floor space required per student
  – 3.0 m² absolute minimum
  – 6.5 m² allowing space for utilities, storage, cleanup, etc.

Lab Layout

• Construction materials should be appropriate for chemicals
  – Benchtops
  – Cabinets & shelving
  – Flooring
  – Avoid metal drainpipes
• Store chemicals and waste securely – not easily spilled or knocked over.
• Keep bulk chemicals in stockroom - not lab.
• Control access to labs, especially during off-hours

Laboratory Modifications or Decommissioning

• When a laboratory is modified or vacated, ensure that:
  – Chemicals have been safely moved to another lab, returned to the stockroom, or properly disposed of.
  – Any contamination has been removed from the:
    • Room (floor, ceiling, walls)
    • Furniture
    • Equipment and fixtures
    • Plumbing system
    • HVAC ductwork

Conclusion

Together we can design, build, and operate safe/secure laboratories!
References


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Principles and Concepts of Laboratory Ventilation

Hazardous Exposure

SOURCE

PATHWAY

RECEIVER

Enclose the Source
Hazardous Exposure

SOURCE  PATH  RECEIVER

Illustration courtesy, Tom Smith, ECT Technologies, Cary NC USA

Ventilation

Safe Worker

Illustration courtesy, Tom Smith, ECT Technologies, Cary NC USA

Reminder: Prioritization of Controls

• Engineering controls
• Administrative controls & Operational work practices
• Personal protective equipment

Engineering Controls

• Change the process
  • Eliminate the hazard
• Substitution
  • Non-hazardous substance for hazardous
    • Trichloroethylene for carbon tetrachloride
    • Toluene for benzene
• Isolate or enclose
  • Process or worker
    • Barrier
• Ventilation
  • Dilution (general ventilation - not good)
  • Local Exhaust Ventilation (LEV)
**Uses of Ventilation**

- Keep gas / vapor concentration below OEL
- Air movement to reduce heat stress
- Keep toxic contaminants below OEL
- Confined space entry
- Limit CO₂ buildup
- Control clean room or hospital environments

*OEL = Occupational Exposure Limit*

**Limitations of Ventilation**

- May require large amounts of air (expensive)
- Outdoor air may create problems
  - Need tempering
  - Heat, cool, dehumidify, humidify
  - May be “contaminated”
- System design
  - Remove contaminant from breathing zone
  - Insufficient air velocity or volume
- Contaminant cleanup or discharge
- Users need training

**Engineering Ventilation Controls**

- General dilution ventilation
  - Not good
- Local exhaust ventilation
  - Preferred

**Use General Dilution Ventilation**

- For Control of:
  - Temperature
  - Harmless Substances
  - Nuisances
  - Odors
Use Local Exhaust Ventilation (LEV)
- To enclose and contain
- When contaminant is toxic
- Employee works near the contamination
- When complete containment/enclosure is not feasible

Local Exhaust Ventilation

LEV Principles
- Enclose source
- Capture contaminant near source
- Keep contaminant out of breathing zone
- Provide adequate make-up air
- Discharge away from air intake

Definitions
- **Hood** – includes any suction device, regardless of shape, that encloses, captures or removes contaminants.
- **Dilution Ventilation** – moves room air around by a fan that is sometimes exhausted to the outside.
- **Local Ventilation (LEV)** – ventilation system that captures and removes emitted contaminants.
System Components

- Hood
- Duct Work
- Optional Air Cleaning Devices
- Fan
- Discharge

System Characteristics

Q3 = Q1 + Q2

Conservation of Mass

Where:
- Q = volumetric flow rate (m^3/s)
- v = velocity (m/s)
- A = Cross Sectional Area (m^2)

Q = vA

Volumetric Flow Rate

Q = vA

Q = Volumetric Flow Rate, m^3/s
v = Average Velocity, m/s
A = Cross-sectional Area, m^2
### Flow Rate Example

For circular ducts:

\[ Q = vA \]

Where:
- \( Q \) is the flow rate
- \( v \) is the duct velocity
- \( A \) is the cross-sectional area

**Example 1:**
- Duct diameter = 1 m
- \( v = 600 \text{ m/s} \)
- What is \( Q \)?

\[ Q = (600 \text{ m/s}) \left( \pi \left( \frac{1\text{ m}}{2} \right)^2 / 4 \right) \]
\[ Q = 471 \text{ m}^3/\text{s} \]

**Example 2:**
- Duct diameter = 0.5 m
- What is the duct velocity?

\[ Q = v \left( \pi \left( \frac{0.5\text{ m}}{2} \right)^2 / 4 \right) \]
\[ v = 2403 \text{ m/s} \]

### System Losses

- **Friction Loss**
  - Rougher surfaces lead to higher velocity
  - \( FL \propto LV^2/d \)
  - \( FL \) units of pipe length

- **Dynamic Loss**
  - Turbulence from elbows or cross-sectional area changes or transition
  - Turbulence at hood entry
    - Coefficient of Entry \( "C_e" \) measures efficiency of hood entry
    - \( DL \) increases with abruptness of elbow or transition
    - \( DL \) units of equivalent pipe length or fraction of VP

- **Pressure losses from system devices**
  - Fans, air cleaners, etc.

### Press Room – Ventilation System

### Local Exhaust Hoods

\[ Q = vA \]

**CAPTURE**

\[ v_{\text{face}} \]
\[ v_{\text{capture}} \]

**ENCLOSURE**
Local Exhaust Hoods

P = Hood perimeter

Canopy Hood – Machine Shop

Portable Welding Hood

Traditional Laboratory Chemical Hood
Special Purpose Hoods Vented to the Outside

Design Goals for Balance Enclosures

- High level of containment
- Stable balance readings
- Ergonomic design, visibility, comfort
- Task specific flexibility
- Energy efficient

- 2' enclosure = 100 CFM (0.047 m³/s) air
- 6' hood = 1200 CFM (0.566 m³/s) air
- 1200 CFM (0.566 m³/s) = $5K/yr.

Flow at Exit and Entry

Hood Capture Velocities

Capture of contaminant is only effective within one (1) duct diameter

<table>
<thead>
<tr>
<th>% Hood Capture Velocity</th>
<th>~100%</th>
<th>~60%</th>
<th>~30%</th>
<th>~15%</th>
<th>~7.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal Velocity Zones</td>
<td></td>
<td></td>
<td></td>
<td></td>
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**Hood Capture Velocities**

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</tr>
<tr>
<td></td>
<td>~60%</td>
</tr>
<tr>
<td></td>
<td>~30%</td>
</tr>
<tr>
<td></td>
<td>~15%</td>
</tr>
<tr>
<td></td>
<td>&gt;7.5%</td>
</tr>
</tbody>
</table>

**Recommended Capture Velocities**

<table>
<thead>
<tr>
<th>CONDITION</th>
<th>EXAMPLES</th>
<th>CAPTURE VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>No velocity, Quiet air</td>
<td>Evaporation from tanks, degreasers</td>
<td>50 – 100 (0.25 – 0.5)</td>
</tr>
<tr>
<td>Low velocity, moderately still air</td>
<td>Spray booths, container filling, welding, plating</td>
<td>100 – 200 (0.5 – 1.0)</td>
</tr>
<tr>
<td>Active generation into rapid air motion</td>
<td>Spray painting (shallow booths), crushers</td>
<td>200 – 500 (1.0 – 2.5)</td>
</tr>
<tr>
<td>High initial velocity into very rapid air motion</td>
<td>Grinding, abrasive blasting, tumbling</td>
<td>500 – 2000 (2.5 – 10.1)</td>
</tr>
</tbody>
</table>

**Design Duct Velocities**

<table>
<thead>
<tr>
<th>CONTAMINANT</th>
<th>EXAMPLES</th>
<th>DESIGN VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vapors, gases, smoke</td>
<td>Vapors, gases, smoke</td>
<td>1000 – 2000, 5.0 – 10.1</td>
</tr>
<tr>
<td>Fumes</td>
<td>Welding</td>
<td>2000 – 2500, 10.1 – 12.7</td>
</tr>
<tr>
<td>Very fine dust</td>
<td>Cotton lint</td>
<td>2500 – 3000, 12.7 – 15.2</td>
</tr>
<tr>
<td>Dry dusts &amp; powders</td>
<td>Cotton dust</td>
<td>3000 – 4000, 15.2 – 20.3</td>
</tr>
<tr>
<td>Industrial dust</td>
<td>Grinding dust, limestone dust</td>
<td>3500 – 4000, 17.8 – 20.3</td>
</tr>
<tr>
<td>Heavy dust</td>
<td>Sawdust, metal turnings</td>
<td>4000 – 4500, 20.3 – 22.9</td>
</tr>
<tr>
<td>Heavy/moist dusts</td>
<td>Lead dusts, cement dust</td>
<td>&gt; 4500, &gt; 22.9</td>
</tr>
</tbody>
</table>
Capture Velocity

- Plain End Opening: \( Q = v(10X^2 + A) \)
- Flanged Opening: \( Q = 0.75v(10X^2 + A) \)
- Slot: \( Q = 3.7 \text{LvX} \)
- Flanged Slot: \( Q = 2.6 \text{LvX} \)
- Booth: \( Q = v\text{WH} \)
- Canopy: \( Q = 1.4v\text{PVX} \)

\( X \) = distance in front of opening
\( L \) = Length
\( W \) = Width
\( H \) = Height
\( v \) = velocity
\( A \) = Area
\( Q \) = Quantity of air

Hood Type Calculations

Plain Opening: \( Q = v(10X^2 + A) \)
Flanged Opening: \( Q = 0.75v(10X^2 + A) \)

\( Q \) = Quantity of air (m³/s)
\( v \) = Velocity of air (m/s)
\( X \) = Distance from hood face to point of contaminant generation (m)
\( A \) = Area (m²)

Hood Calculations: Example

Determine the air flow required to capture Trichloroethylene vapor from a degreaser using a 30 cm diameter plain end duct whose opening is 45 cm from the vapor source.

\( A = \pi \frac{(30 \text{ cm}/100)^2}{4} = 0.071 \text{ m}^2 \)
\( Q = v(10X^2 + A) \)
Assume a capture velocity of 0.5 m/s
\( Q = 0.5 \text{ m/s} \left( (10 \times 0.45^2) + 0.071 \text{ m}^2 \right) \)
\( Q = 0.5 \text{ m/s} (2.096 \text{ m}^2) = 1.048 \text{ m}^3/\text{s} \)

Hood Calculations: Example

Determine the air flow required to capture Trichloroethylene vapor from a degreaser using a flanged slotted hood with a 4 cm slot, 1 m long, located on the back side of the dip tank 0.5 m from the front edge.

\( Q = 2.6L\text{vX} \)
\( Q = 2.6(1 \text{ m})(0.5 \text{ m/s})(0.5 \text{ m}) \)
\( Q = 0.65 \text{ m}^3/\text{s} \)

The flanged slotted hood uses much less air and it is probably more effective overall.
Fan Speed and Air Flow

Fan rated to deliver 5.0 m³/s of air running at 400 RPM. If fan speed increases by 25% to 500 RPM, what is the new air flow?

\[ Q \propto \text{RPM} \]

\[ Q_2 = Q_1 \left( \frac{\text{RPM}_2}{\text{RPM}_1} \right) \]

\[ Q_2 = 5 \left( \frac{500}{400} \right) = 6.25 \text{ m}^3/\text{s} \]

Hood Exhaust

- Height
- Discharge velocity
- Configuration
Engineering Controls: Avoid Exhaust Recirculation

Potential Issues
- Insufficient air volume
- Too much air flow
- Wrong location
- Wrong configuration
- Bad hood design
- Duct velocity too low
- Insufficient make up air
- Clogged system
- Noise

Acknowledgements
- Tom Smith, Exposure Control Technologies, Cary NC USA http://www.labhoodpro.com/
- Nelson Couch, PhD, CIH, CSP, Triangle Health & Safety Inc., Durham, NC USA ncouch@earthlink.net
Laboratory Chemical Hoods:
How they work & when they don’t.

Laboratory Chemical Hood

- Also called a fume hood or fume cupboard
- Designed to limit exposure to hazardous or unpleasant aerosols
- First used by alchemists 500 years ago

Improper Hood Use

- Also called a fume hood or fume cupboard
- Designed to limit exposure to hazardous or unpleasant aerosols
- First used by alchemists 500 years ago
Control Concept

SOURCE

PATH

RECEIVER

LEV Objectives

- Maximize Containment
- Minimize Contamination
- Redundancy is the Key

LEV Implementation

- Identify/Characterize Contaminant
- Characterize Air Movement
- Identify Alternative Controls
- Choose Most Effective Control
- Implement Control
- Evaluate Control
- Maintain Control

LEV Capture Ability

- Hood configuration (type of hood)
- Extent of enclosure
  (e.g., glove boxes completely enclose)
- Air movement in hood
  (smooth, laminar, non-turbulent)
Duct Design

- Provide adequate capture velocity
  - Usually 80-120 fpm (0.4 - 0.6 m/s)

- Maintain duct transport velocity
  - For chemical laboratories ~ 2500 cfm (1.2 m³/s)

Duct Design, cont'd.

- Keep system balanced,
  - i.e., equalize supply and return air
  - match airflow among manifolded hoods

- Minimize power consumption
  - i.e., conserve energy
  - save money

LEV Hood Design Requirements

- Capture emissions close to source.
- Move contamination away from breathing zone.
- Consider existing air movement when locating hood.
- Minimize air movement in source area.
- Should not interfere with work.

Laboratory Hoods

Laboratory hoods and ventilation are the basis of engineering controls.

But they must be properly: selected, located, used, and maintained.
Hood Location Requirements

- As near to contamination source as possible
- So contamination moves away from operator
- Minimize cross-drafts
- Don’t place near windows and doors
- Don’t place near air conditioning/heater diffuser
- Doesn’t interfere with other workers
- Locate out of traffic flow
- Place near rear of laboratory

Problem Cross-drafts

A person walking at 2-3 mph (0.9-1.3 m/s) generates cross drafts of 250 fpm (1.3 m/s) that can interfere with hood capture

<table>
<thead>
<tr>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Good" /></td>
<td><img src="image2.png" alt="Fair" /></td>
<td><img src="image3.png" alt="Poor" /></td>
</tr>
</tbody>
</table>

Principles of Hood Design and Operation

- Enclose as much of the operation as possible
- Place utility controls (gas, electric) outside or as near hood front as possible
- Hood lights should be vapor tight
- Mount hood motor outside building and away from building air intakes
- Don’t use hoods for uses not intended (e.g., perchloric acid digestion, radioisotopes)
- Ensure duct material compatible with exhausts
- Don’t use without indication it is working properly
Hood Design & Operation, cont’d.

- Don’t put your head in the hood.
- Use proper PPE (gloves, eyewear, etc)
- Place large equipment above surface on 5 cm blocks to allow uniform air flow
- Lower sash height to 30 - 50 cm during operation
- Keep sash fully closed when not in use
- Use liner or tray inside hood to contain spills

Laboratory Hood Types

- Constant Air Volume (CAV)
  - Traditional/Standard/Conventional
  - Bypass
  - HOPEC (horizontal/vertical sash)
  - Auxiliary Air (not recommended for Lab operations)

- Variable Air Volume (VAV)

Hood Design & Operation, cont’d.

- Work in the center of hood and 15 cm in from hood sash.
- Don’t store chemicals or equipment in hood.
- Don’t block baffles (slots).
- Maintain hood regularly (check fan belt, lubricate motor).
- Regularly evaluate hood (flow rate, mark operating sash height).
- Reports problems, concerns, malfunctions immediately.

Traditional Constant Volume Hood

- All make up air enters through hood face.
- Air exhausted is constant regardless of size of face opening or sash height.
- Volume of air movement is constant but velocity varies with sash height.
**Constant Volume Bypass Hood**
- Make up air enters through face and through a bypass.
- Bypass opening varies in size as sash is opened or closed.
- As sash moves, an almost equivalent area is uncovered to maintain a constant open area, hence, a constant volume of air movement through the face is achieved.

**Auxiliary Air Hood**
(not recommended for Lab operations*)
- Designed to reduce energy consumption.
- Discharges unconditioned make-up/auxiliary air from outside directly above and over user in front of hood.
- Uncomfortable to use and can produce turbulence at hood face.

* According to ANSI Z9.5

**HOPEC Hood**
(Hand Operated Positive Energy Control)
Combination Horizontal/vertical sash limits sash opening to no more than 50%.
Maintains constant air volume and limits energy consumption.

**Variable Air Volume (VAV) Hood**
Uses mechanical and electronic controls to maintain constant air velocity.
Interfaces with room supply air to conserve energy by maintaining constant face velocity.
Uses complicated electronic components that require special training to maintain.
**Specialized Hoods**

- Perchloric acid (with water wash down)
- Radiological (with special filters)
- Floor level (improperly called walk-in)
- Distillation/California hoods (~1.5 ft or 0.5m above floor)
- Canopy hoods (not suitable for most lab operations)
- Slot hoods
- Ductless fume hoods
- Vented enclosures or special purpose hoods
- Glove Boxes (complete enclosure)
- Biological Safety Cabinets (BSC)
Example: Canopy Hood

Glove Boxes
- Glove boxes are used when the toxicity, radioactivity level, or oxygen reactivity of the substances under study pose too great a hazard for use within a fume hood.
- The major advantage is protection for the worker and the product.

Special purpose vented hood
- Chemical weighing station
- Bulk powder transfer station

Ductless Hoods
**Ductless Hoods**

Should only be used in laboratories with:
- Small quantities of known non-volatile substances.
- Only with HEPA filters
- Never with volatile substances
- Unless breakthrough time for the specific chemical being used is known, carbon filters are unreliable.

---

**Specialized Hoods**

- Dust hood, Animal feed
- Downdraft table
- Snorkel hood
- Slot Hood

---

**Biological Safety Cabinets (BSC)**

Several types/classes and configurations.

Designed to protect the sample, and sometimes the worker, from biological contamination.

Most types not suitable for hazardous, volatile chemicals.

Often not vented to the outside.


---

**Hood Problems and Pitfalls**

- **Face velocity**
  - Recommended 80 - 100 fpm (0.4 - 0.5 m/s)

- **Air changes/hour**
  - Recommended 6 – 10 / hour

*Neither of these measurements can guarantee hood capture or containment.*
Hood Evaluation

- Face Velocity, a necessary but not sufficient condition.
- Smoke Tubes
- Smoke Candles
- Incense
- ASHRAE 110-1995 Test ($S_{fe}$)
- Protection Factors (300-10,000):

$$PF = \frac{\text{Contaminant Concentration in Exhaust Air}}{\text{Contaminant Concentration in Breathing Zone}}$$

Ventilation System Evaluation

- Smoke sources
  - Visualize air movement
  - Assess capture effectiveness
- Smoke tubes
- Smoke candles
- Theatrical smoke generators
- Incense sticks

Velocity measurements
- Anemometer/velometer
  - fpm or m/s
  - Directional
- Hot-wire anemometer
  - fpm or m/s
  - Non-directional

Lab hood performance testing evaluates containment of contamination. How do we determine containment?
- Is face velocity the right measurement?
- Studies show that 59% of the hoods passed face velocity criteria, but only 13% of these hoods met ASHRAE 110 tracer-gas standards.
- 30% - 50% of hoods leaking excessive levels of contaminants pass face velocity tests.
- Lab hoods with face velocities as low as 50 fpm (0.25 m/s) can provide protection factors 2,200 times greater than hoods with face velocities of 150 fpm (0.76 m/s).
ASHRAE 110 Containment Test

- Measures containment using SF₆ as a tracer gas
- SF₆ is generated inside the hood at 4L/min.
- A mannequin with a detector in the breathing zone (mouth) is placed outside the hood
- The detector is connected to a recorder
- The hood is also tested with smoke
- The hood is subjected to a walk-by test
- Effect of opening & closing sash is determined
Conclusions

- Ensuring laboratory hood safety depends on many factors including:
  - Hood design
  - Hood use
  - Lab design
  - System operation

Summary of Results

- Improved Aerodynamics and Airflow Patterns
- Equivalent Performance (Containment) as Typical Fume Hoods
  - 0.175°Fm/s as Manufactured
  - <0.1°Fm/s as Switched and as Used
  - Better Containment With Slides Fully Open
  - Less Dependence on Sliding Height
- Minimum Face Velocity of At Least 60 fps
- Hull Affected by External Factors
  - Cross Drafts greater than 0.1°Fm/s
  - Perpendicular Cross Drafts are worse than Horizontal Drafts
  - Hoodlocation and Perforated Challenge Air Influence Containment
  - Traffic Past Hood Can Influence Containment
- Not All Fume Hoods Perform The Same
- Fume Hood Manufacturers Need Better Accuracy and Precision at Low Velocities

Acknowledgements

- Tom Smith ECT, Inc., Cary NC USA
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- Flow Sciences Inc, Leland NC USA
- Knutson Ventilation, Edina MN USA
- AirClean Inc, Raleigh NC USA
**Chemical Management**

**Best Practices**

- Reduces hazardous waste
- Reduces cost
  - New purchases
  - Waste disposal
- More efficient
- Improves security
  - Insider threat
  - Outsider threat
- Facilitates environmental compliance
- Improves quality of research
- Improves quality of lab instruction

**Chemical Management is a Best Practice for Safety and Security**

**Proper chemical management program has several essential elements**

- Source reduction
- Procedure for chemical ordering and disposal
- Inventory and tracking
- Storage in stockrooms
- Access control
- Recycling of chemicals, containers and packages
Plan experiments in advance!

What chemicals are needed?
How much is needed?
How will the chemicals be handled?
What are the reaction products?
How will the chemical be stored?
How will disposal take place?

Inventory management

Less is Better!

- Order only what you need
- Reduce size of experiment
- It cost less to store
- It cost less to dispose

Substitute reagents to reduce waste

- Citrus based solvents for xylene in histology lab
- Peracetic acid for formaldehyde for cleaning kidney dialysis machines
- Non mercury thermometers
- Enzyme and peroxide based cleaners for chromerge (NoChromix)
- When purchasing automated equipment think of chemical waste

Best practice - ordering and stocking chemicals

- See if your institution already has it (surplus)
- Order minimum needed (large quantities are not a bargain)
- Check on special storage (refrigeration, dry box...)
- Mark the receipt /open date (unstable chemical)
- Can it eventually be disposed of (rad waste, mixed waste)
Ordering chemicals - chemical inventory

- Database or Spreadsheets are tools to track the chemical inventory
  - Barcoding can be used
  - Chemicals can be found easily
  - Chemical ages can be tracked
  - Chemical standards maintain traceability
  - Disposal can be documented
- Physical reconciliation
  - Assures accuracy of database
  - Provides visual inspection of chemical condition

Inventory and tracking

Database or spreadsheet designs

Home made – Access or Excel programs
Freeware – Based on Access or Excel
Commercial – Chemicals and MSDS included

Database helps safely track and report chemical storage and use

Searches and Reports:
- Find an (M)SDS
- Chemical Inventory Search Menu
- Chemical Regulatory Reports Search Menu
- Find Chemical Storage Locations

Transfers, Removal, Verification and Inventory Entry:
- Transfer or Remove a Bar-coded Chemical from the Inventory
- Verify Chemical Inventory Menu
- Add Chemical Inventory
- Chemical Exchange Menu

Procedures, Forms and Links:
- See Inventory procedures, forms and other documents
- See Other Chemical Related Links

Inventory queries

Chemical or tradename search
CAS number search
Ingredient search
Location/organization search
Location owner search
Requester search
Barcode search
Query result for toluene – barcode, location, department, quantity and order date

<table>
<thead>
<tr>
<th>BARCODE</th>
<th>LOCATION</th>
<th>DEPT</th>
<th>QUANTITY</th>
<th>UNIT</th>
<th>Purchase Date</th>
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<tr>
<td>AQ00600682</td>
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<td>1725</td>
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<td>L</td>
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<td>mL</td>
<td>11/20/2006</td>
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<td>NM/518/1302</td>
<td>1131</td>
<td>100</td>
<td>mL</td>
<td>11/20/2006</td>
</tr>
</tbody>
</table>

(M)SDS and Certificates of Analysis may also be included

Chemicals likely to be useful in other labs

**ACIDS**
- Acetic acid (glacial)
- Hydrochloric acid
- Sulfuric acid

**SOLVENTS**
- Dichloromethane (methylene chloride), Acetone, Chloroform, Ethyl acetate, Glycerol, Hexanes, Isopropyl alcohol, Methanol, Petroleum ether, Toluene, Xylenes

**OXIDIZERS**
- Bromine, Potassium chlorate, Potassium dichromate, Silver nitrate

**POISONS**
- Indicators, Iodine (solid or solution), Metals (powders, dust, shot)
- Sodium, calcium, silver, and potassium salts

Excess chemicals are made available to others and can be searched

<table>
<thead>
<tr>
<th>CHEMICAL NAME</th>
<th>MSDS</th>
<th>QTY</th>
<th>STATE</th>
<th>PURCHASE DATE</th>
<th>OPEN?</th>
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<tbody>
<tr>
<td>DEVCON 5 MINUTE EPOXY KIT</td>
<td>NL203800</td>
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<td>Liquid</td>
<td>07/25/2001</td>
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<tr>
<td>5 MINUTE EPOXY KIT</td>
<td>NL203800</td>
<td>2.5 OZ</td>
<td>Liquid</td>
<td>08/06/2003</td>
<td>Not Open</td>
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<tr>
<td>TOLUENE</td>
<td>OHS23590</td>
<td>500.0</td>
<td>ML</td>
<td>03/25/1999</td>
<td>Not Open</td>
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<tr>
<td>TOLUENE</td>
<td>OHS23590</td>
<td>500.0</td>
<td>ML</td>
<td>03/25/1999</td>
<td>Not Open</td>
</tr>
</tbody>
</table>

Inventory management

Less is Better! It’s Safer!

It may be cheaper to order diethyl ether in large containers

But, if it’s opened for a long time—peroxides can form!
Inventory management – chemical aging

• How old are your chemicals?
• Some chemicals degrade over time
  – rotate stock
  – label & date
• Chemical assays have expiration dates

Explosives and Reactives

Examples:
  – Peroxide-forming - ethers
  – Perchlorate-forming – perchloric acid
  – Water/moisture sensitive – Na, K, Li, LAiH, flammable metals

Control measures:
  – Inventory control
  – SOPs, inspections

Inventory management

-Peroxide Forming Chemicals-
Even with inhibitors they can become dangerous over time
- discard or test if unsure
- label & date when received, when opened, and provide expiration date

Peroxide test kits and strips should be available

Peroxide forming chemicals

• Peroxide formation is caused by an autoxidation reaction.
• The reaction is initiated by light, heat, introduction of a contaminant or the loss of an inhibitor (BHT).
• Inhibitors slow, but do not stop peroxide formation.
• Most organic peroxide crystals are sensitive to heat, shock, or friction.
• It is important not to let peroxide forming chemicals evaporate to dryness or accumulate under screw caps.

-R-O-O-R-
Peroxide forming chemicals

Peroxides can explode when exposed to thermal or mechanical shock
Examples: ethers, dioxane, tetrahydrofuran

References:
There are excellent websites on peroxide forming chemicals and their hazards, use, storage, and disposal. For example, see:
http://www.med.cornell.edu/ehs/updates/peroxide_formers.htm

Chemical storage

- Protect chemicals during normal operations
- Protect chemicals during unexpected events
  - Floods
  - Tidal waves
  - Earthquakes
  - Typhoons
  - Hurricanes

Chemical storage: Basic concepts

- Separate incompatible chemicals
- Separate flammables/explosives from ignition sources
- Use flammable storage cabinets for large quantities of flammable solvents
- Separate alkali metals from water
- Separate acids and bases

Use flammables storage cabinets
Chemical storage: Basic concepts

- Store nitric acid separately
- Store large containers on bottom shelves
- Lock up drugs, chemical surety agents, highly toxic chemicals
- Do not store food in refrigerators with chemicals

Chemical storage: Gas cylinders

- Secure (chain/clamp) and separate gas cylinders
- Screw down cylinder caps
- Store in well-ventilated area
- Separate & label empty cylinders
- Store empty cylinders separately
- Separate flammable from reactive/oxidizing gases

Compressed Gas Cylinders

- Uses
- Types
- Hazards
- Control Measures
  - Inventory control
  - Procurement authorization
  - Training
  - Inspection

Improper gas cylinder storage
Damage from Gas-cylinder fire

An Accident Waiting to Happen

CSB video: Compressed gas fire

Dangers of Propylene Cylinders in High Temperatures

Fire at Praxair Distribution, Inc.

St. Louis, MO, June 24, 2003
Chemical storage: Good practices

- Limit access
  - Label “Authorized Personnel Only”
  - Lock area/room/cabinets when not in use
- Be sure area is cool and well ventilated
- Secure storage shelves to wall or floor
- Shelves should have a 3/4” front lip
  - In earthquake territory, have a rod several inches above shelf

Chemical storage: Bad practices

- Do Not Store Chemicals
  - on top of cabinets
  - on floor
  - in hoods
  - with food or drinks
  - in refrigerators used for food
  - where there are wide variations in temperature, humidity or sunlight

Chemical storage: Containers

- Don't use chemical containers for food
- Don't use food containers for chemicals
- Be sure all containers are properly closed
- Wipe-off outside of container before returning to storage area
- Transport/carry all containers safely
  - Preferably use outer protective container

Improper chemical storage

- Never use hallways for storage
- Safety Hazard!!
- Blocks exit path in emergencies!!!
Chemical storage: Good practices

• Separate incompatible chemicals
  – Organize chemicals by compatible groups
  – Alphabetize chemicals only within compatible groups

Suggested shelf storage groups:

Organics

• Acids, anhydrides
• Alcohols, amides, amines
• Aldehydes, esters, hydrocarbons
• Ethers, ketones, halogenated hydrocarbons

• Epoxies, isocyanates
• Azides, peroxides
• Nitriles, sulfides, sulfoxides
• Cresols, phenols

Inorganics

• Metals, hydrides
• Halides, halogens, phosphates, sulfates, sulfides
• Amides, azides, nitrates, nitrites
• Carbonates, hydroxides, oxides, silicates
• Chlorates, chlorites, perchlorates, peroxides
• Arsenates, cyanides, cyanates
• Borates, chromates, manganates
• Acids
• Arsenics, phosphorus, sulfur

Best practice: access control

• Proper training of chemical handling personnel
• Only trained and approved personnel
  • have access to stock room and keys
  • administrative privileges to inventory and database
• Locked doors and cabinets for controlled substances
  • Radioactive materials
  • Drugs and consumable alcohol
  • Explosives (special handling facility)
  • Dual use chemicals
  • Hazardous waste - high toxicity chemicals

References

“Less is Better,” American Chemical Society, Washington DC, 2003, available online:
http://portal.acs.org/portal/cpc.cemnt7?absc=true&node=portal&popup=PP
SUPERARTICLE&node_id=92106&use_sec=false&sec_url_var=region1&uid=f97cb85-8b33-4588-5b0b-ff5b9ca0ca31


http://www.nap.edu/catalog.php?record_id=4911

Other Hazards in a Chemical Laboratory

Physical Hazards
Conditions, besides chemical, biological or radiological conditions or circumstances, that can cause injury, illness and death:

- Fire / Asbestos
- Centrifuges
- Cryogenics
- Ergonomic
- Office
- Physical stress/strain
- Construction
- Noise
- Heat/cold
- Sunlight
- Non-ionizing radiation
- Mechanical
- Electrical
- Housekeeping
- Spills/trips
Asbestos-Containing Materials

- Gloves
- Lab hoods
- Lab benches
Centrifuge Equipment

- Uses
- Hazards
- Control of hazards
  - Only authorized users can use equipment
  - Users must be trained
  - Assign responsibility to lab tech
  - Include in periodic lab inspections

- Rotor
- Drive Shaft
- Motor
- Cabinet provides varying degrees of protection
Centrifuge Safety

Don't overload
Check rotor for cracks

Keep rotor and centrifuge clean
Set it up right
Chemical storage: Cryogenics

- Store cryogenics separately from other chemicals
- Store cryogenics (liquid nitrogen) & dry ice in well ventilated areas
- Use proper PPE (including eye protection) when handling & moving cryogenics
- Do not use cryogenics in closed areas

Cryogens

- What are they?
- Uses
- Hazards
- Control
  - training
  - inspection
**Cyrogen Storage**

Exploding liquid nitrogen cylinder ruins lab.

**Dry Ice**

- What is dry ice?
- Uses
- Hazards
- Control measures

**Housekeeping**
Do not use hoods for storage!

Don't block hood air flow.

Place large equipment in a hood on 5 cm blocks to allow air flow around and under equipment.
Safety shields can block airflow and reduce hood effectiveness.

Access to emergency equipment is essential. Always check that equipment is not blocked.

Don't block hallways and exits!

Food is never allowed in laboratories.
What’s Wrong With This Picture?

Open-toed shoes should not be allowed in laboratories.

Employees should not wear gloves, lab coats or other PPE outside the lab.

Working Alone/Unattended Operations

- Working Alone
  - Avoid!
  - Murphy’s Law will get you!
    (Anything that can go wrong, will go wrong!)
  - Use the “Buddy System”

- Unattended Operations/Reactions
  - Caution! Prime sources of fires, spills and explosions
  - Check periodically!
  - Fail-safe provisions
  - Leave the lights on to indicate the presence of an unattended activity
  - Post appropriate signs and emergency phone #’s
  - Notify those potentially impacted by malfunction

Electrical Hazards

- Can be a significant problem
  - Frayed cords, no UL-listing, overloaded circuits
  - Static electricity

- Hazards
  - Fires, electrical shock, power outages

- Control
  - Inspect, act immediately, education
Check to see that all outlets are grounded and that the polarity is correct.

Storage should be at least 1 m from electrical panels, mechanical rooms, air ducts, heaters, light fixtures.

Don't store combustibles in mechanical rooms or electrical closets.

In emergencies it may be necessary to access these panels quickly.

Multi-outlet strips must be approved and not used for high-amp equipment.
(e.g., ovens, refrigerators)
Don’t Do This…

Heating Mantles
- Uses
- Hazards
- Unshielded rheostats
- Control measures

Ergonomics
- Types of hazards
  - Why be concerned with Ergonomics?

Awkward Posture
- Too far away
- Too low
- Too high
Repetitive Motion Disorders

About 15 to 20% of workers in jobs requiring highly repetitive motion of shoulders, arms, wrists or hands develop repetitive motion disorders.

<table>
<thead>
<tr>
<th>Disorder</th>
<th>Affected Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpal Tunnel Syndrome</td>
<td>Wrist</td>
</tr>
<tr>
<td>Tendonitis</td>
<td>Elbow, wrist, hand</td>
</tr>
<tr>
<td>Tenosynovitis</td>
<td>Elbow, wrist, hand</td>
</tr>
<tr>
<td>Epicondylitis</td>
<td>Tennis elbow</td>
</tr>
<tr>
<td>Reynaud’s phenomenon</td>
<td>“White finger”</td>
</tr>
<tr>
<td>Ulnar neuropathy</td>
<td>Fingers</td>
</tr>
</tbody>
</table>

Freezers

- Ultra low temperatures
  - -20°C, -80°C
  - Upright vs. walk-in
- Emergency power
- Labels
- Precautions
  - No dry ice in freezers!
  - Improper storage
- PPE

Glassware Handling

- Potential Hazards
  - Ergonomics
  - High temperature
  - Broken glassware
  - Improper use
- Control
  - Inspection
  - Training

Beware of contaminated Glassware, especially if broken!
High Pressure Reactions

- Experiments carried out at pressures above 1 atmosphere (~1 bar, 760 Torr, ~100,000 Pa).
  - Use of supercritical fluids (CO₂)
- Hazards
  - Explosions, equipment failure
- Control Measures
  - SOPs, training, engineering controls, inspection
  - Dry runs

Vacuum Work

- Uses
  - Aspiration
- Hazards
  - Injury due to glass breakage
  - Toxicity of chemical contained in vacuum
  - Fire following flask breakage
  - Contaminated pump oil
- Control Measures
  - SOPs, inspection, education
Mechanical hazards like open drive belts with pinch points must have shields and guards.

Oil pumps need drip pans to contain oil.

Noise

- Elevated noise levels can be a problem.
- Potential Hazards
  - Examples: bone-cutting saws, mechanical water aspirators, sonicators, pumps.
- Control Measures
  - Inspections, PPE, warning labels, training.

Magnetic Fields

- Uses – NMR, MRI
- Hazards
  - Magnetic field
  - High voltage
  - Cryogenic liquids
    - e.g., nitrogen, helium
  - Other hazardous materials in lab
- Control Measures
  - Control access to area
  - Training
  - Warning signs
**Ionizing vs. Non-ionizing Radiation**

- **IONIZING RADIATION**
  - Particulate or electromagnetic
  - Charged (α, β) or uncharged (γ, X, n)
  - Causes ionization of atoms or molecules

- **NON-IONIZING RADIATION**
  - Electromagnetic (UV, IR, MW, RF)
  - Can not ionize atoms or molecules

**Common Uses of Ionizing Radiation**

- **Research & Development**
  - ¹⁴C, ³⁵S, ³²P
- **Medical**
  - X-Rays

**Electron Microscopes**

- **Types**
  - SEM, TEM
- **Hazards**
  - X-rays
- **Control of hazard**
  - Periodic maintenance
  - Conduct radiation survey
  - Include in personnel radiation safety program
Protect yourself by:

- **TIME** – Limit time near source

- **DISTANCE** – Stay away
  \[ I_2 = I_1 \left( \frac{d_1}{d_2} \right)^\gamma \]

- **SHIELDING** – Absorb energy

- **CONTAMINATION CONTROL**

### Shielding Materials

<table>
<thead>
<tr>
<th>Radiation Type</th>
<th>Shielding Materials</th>
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</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>Paper, Plastic</td>
</tr>
<tr>
<td>Beta</td>
<td>Plastic, Lead or concrete</td>
</tr>
<tr>
<td>Gamma &amp; X-Rays</td>
<td>Water, Lead or concrete</td>
</tr>
<tr>
<td>Neutron</td>
<td>Water</td>
</tr>
</tbody>
</table>

### Non-Ionizing Radiation

- **UV, Visible, IR, Lasers**
- **Hazards**
  - Skin erythema
  - Eye injuries
- **Control Measures**
  - Training, PPE, warning signs and labels, interlocks
Radio-frequency & Microwaves

- **Uses**
  - RF ovens and furnaces
- **Hazards**
  - Cataracts, sterility
  - Arcing – use of metal in microwave
  - Superheating of liquids
  - Explosion of capped vials
- **Control Measures**
  - SOPs, education, inspection

Robotics

- **Free-moving parts**
  - “Struck by” injuries
- **Noise**
- **Lasers**
- **Aerosol Generation**

Sharps, Needles, Blades

- **Hazards**
  - Needlesticks
  - Cuts
  - Contamination
Sharps, Needles, Blades

- Control Measures
  - SOPs
  - Training
  - Modify work practices
  - Engineering Controls

Slips, Trips, Falls

- Most common injuries
- Causes
  - Chemical spills and leaks
  - Improper work practices
- Control Measures
  - SOPs, proper equipment, effective communication, engineering controls

Control of Hazards

- Think!
- Develop SOPs, safety manual, policies
  - reviewed and approved by management
- Research protocol review
- Install engineering controls
- Provide PPE
- Provide training
- Conduct inspections, routine & unannounced with lab supervisor
- Document and follow-up
- Take action

Any Questions?
Questions?
Open Discussion
Homework