Chemical
SAFETY AND SECURITY TRAINING

Chemical Safety and Security Officer Training

Bangkok, Thailand
October 2010

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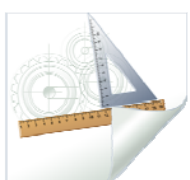
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy's National Nuclear Security Administration

Sandia National Laboratories

Principles and Concepts of Laboratory Design

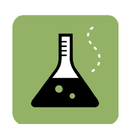
Purpose of Laboratory Design

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**



Barriers to Good Lab Design


Cost

Poor Communication

Lack of Scientific Knowledge

Complicated Project

Trade-offs

Personalities

Maintenance

Good Laboratory Design

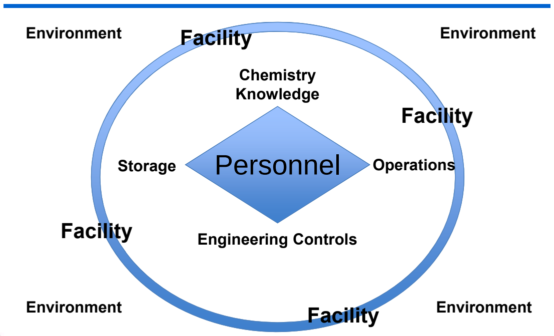
Based on:

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)

↕ (iterative process)

Interpretation
(of requirements into design criteria)

↕ (iterative process)

Design
(translates specifications into pragmatic reality)

↕

Construction
(to accomplish goal)

Major US Standards & Guidelines

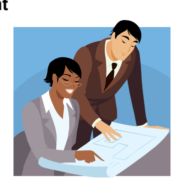
- ANSI Z9.5
  - American National Standards Institute, Z 9.5 Laboratory Ventilation Standard
- NFPA
  - National Fire Protection Association
- BOCA
  - Building Officials Code Association
- ASHRAE 110
  - American Society of Heating, Refrigeration and Air Conditioning Engineers, Standard 110 for Testing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

Architectual 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

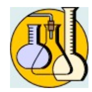
- Architectural
- HVAC*
- Safety and Security
  - Fire
  - Emergencies
  - Exposures
  - Access/exit control (facility, chemicals, equipment)

(* 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



Type of Work/Research

Type of Hazards

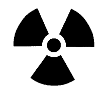
Type of Wastes

Chemical

Biological

Radiation

High Voltage



Safety/Security Information Needed for Lab Design, cont'd.

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

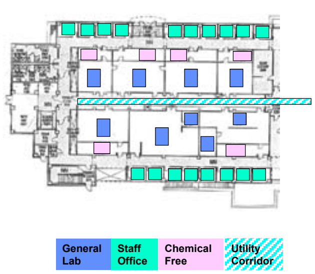
- Sample preparation and storage area
- Segregate sample digestion using acid-specialized laboratory hoods
- Segregate solvent extraction to reduce vapor contamination
- Proper eyewash placement
- Adequate egress
- Waste storage area
- Gas bottle storage

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

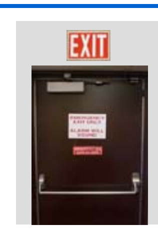
Building Layout: Corridors

- 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

Building Layout: Compressed Gases

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

Building Layout: Chemical Waste

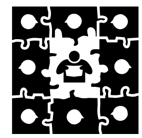
- Large volumes of chemical waste should be stored in areas with fewer people
  - Access restricted to responsible personnel
  - Locked when unattended
  - Divided into chemically compatible groups
  - Provide safety equipment and alarms

Building Layout: Chemical Waste

- Waste collection area in teaching/research labs:
  - Convenient student use
  - Emptied/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



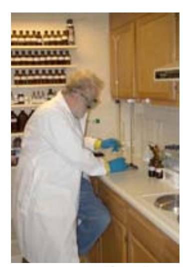
Current Trends in Laboratory Design of Safety/Security Concern

- 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

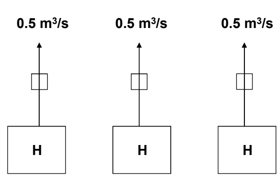
Laboratory hood design and ventilation are discussed in detail in later presentations.

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.

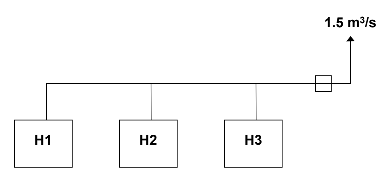
Hood Manifold Considerations

Single Hood - Single Fan



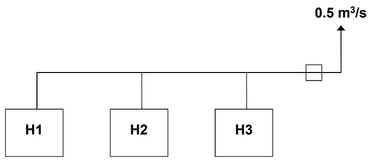
Hood Manifold Considerations

Manifold: 3 Hoods, 1 Fan



Hood Manifold Considerations

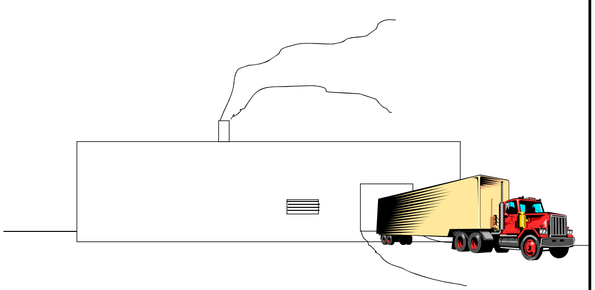
Hood Diversity = 33%



Avoid re-entrainment

Disperse emissions straight upward and downwind!

Ventilation Design: Avoid Exhaust Recirculation



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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 m^2 absolute minimum
  - 6.5 m^2 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!

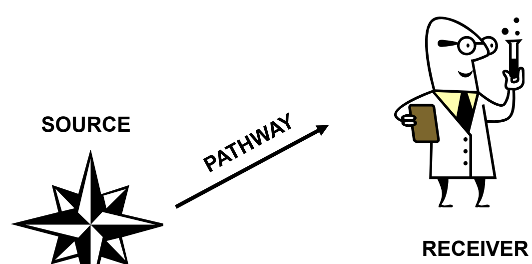
References

- "Prudent Practices in the Laboratory: Handling and Disposal of Chemicals," National Academy Press, 1995, ISBN 0-309-05229-7 also available online: http://www.nap.edu/catalog.php?record_id=4911
- "Laboratory Design, Construction, and Renovation: Participants, Process, and Product," National Academies Press, 2000, ISBN 0-309-06633-6, Also available online: http://www.nap.edu/catalog.php?record_id=9799
- "Handbook of Chemical Health and Safety", Robert J. Alaimo, Ed., Oxford University Press, 2001, ISBN 0-8412-3670-4
- "Guidelines for Laboratory Design: Health and Safety Considerations, 3rd edition" Louis J. DiBerardinis, et al., Wiley, 2001, ISBN 0-471-25447-9

BREAK

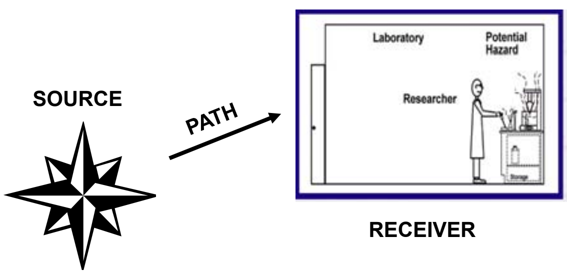
Principles and Concepts of Laboratory Ventilation

Hazardous Exposure



Enclose the Source

Hazardous Exposure



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Ventilation

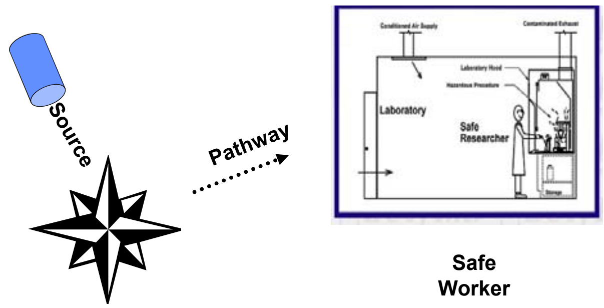


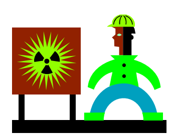
Illustration courtesy, Tom Smith, ECT Technologies, Cary NC USA

Reminder: Prioritization of Controls

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

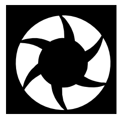
Engineering Controls

- Change the process
  - Eliminate the hazard
- Substitution
  - Non-hazardous substance for hazardous
    - **Trichloroethlyene 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 CO_2 buildup
- Control clean room or hospital environments

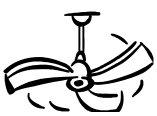


OEL = Occupational Exposure Limit

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 contaminate from breathing zone
  - Insufficient air velocity or volume
- Contaminant cleanup or discharge
- Users need training

Engineering Ventilation Controls



General dilution ventilation

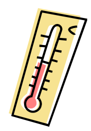
Not good

Local exhaust ventilation

Preferred

Use General Dilution Ventilation

- For Control of:
  - Temperature
  - Harmless Substances
  - Nuisances
  - Odors



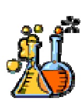
Use Local Exhaust Ventilation (LEV)

- 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**

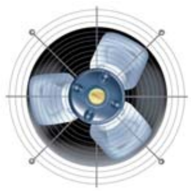


Definitions

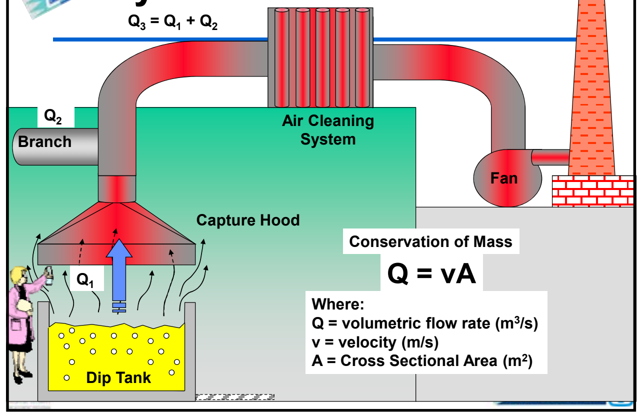
- **Hood** – includes any suction device, regardless of shape, that encloses, captures or removes contaminants.
- **Dilution Ventilation** – moves room air around by a fan that is sometimes exhausted to the outside.
- **Local Ventilation (LEV)** – ventilation system that captures and removes emitted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

System Components

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



System Characteristics



Q = vA

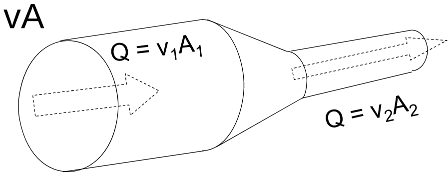
Q = volumetric flow rate of air (m^3/s)

v = velocity of air through an area (m/s)

A = cross sectional area air flows through (m^2)

Volumetric Flow Rate

$Q = vA$

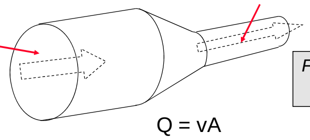


Q = Volumetric Flow Rate, m^3/s
v = Average Velocity, m/s
A = Cross-sectional Area, m^2

Flow Rate Example

Duct diameter = 1 m
v = 600 m/s
What is Q?

Duct diameter = 0.5 m
What is the duct velocity?



For circular ducts
$A = \pi d^2/4$

$Q = vA$

$Q = (600\ m/s)(\pi[1m]^2/4)$

$Q =$ **471 m³/s**

$Q = vA$

471 m³/s $= v\ (\pi[0.5m]^2/4)$

v = 2403 m/s

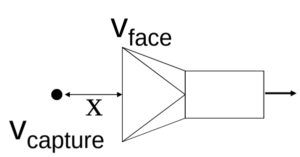
System Losses

- **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

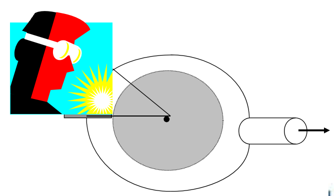
Local Exhaust Hoods

CAPTURE

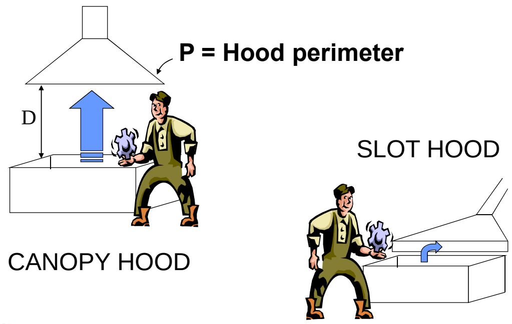


$Q = vA$

ENCLOSURE



Local Exhaust Hoods



Canopy Hood – Machine Shop

Portable Welding Hood

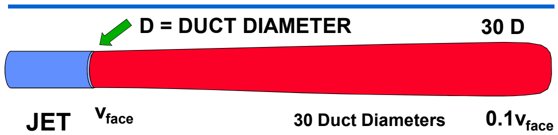
Traditional Laboratory Chemical Hood

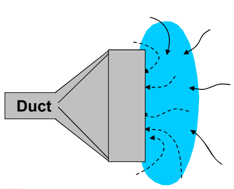
Special Purpose Hoods Vented to the Outside

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 m^3/s) air
  - 6' hood = 1200 CFM (0.566 m^3/s) air
  - 1200 CFM (0.566 m^3/s) = $5K/yr.

Flow at Exit and Entry



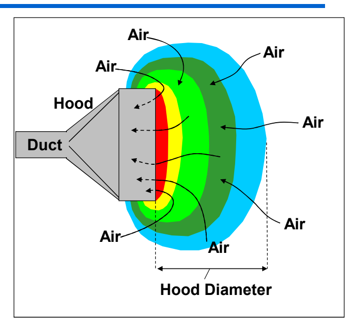


Capture of contaminant is only effective within <u>one (1) duct diameter</u>

Hood Capture Velocities

Equal Velocity Zones

% Hood Capture Velocity	
(red)	~100%
(yellow)	~60%
(green)	~30%
(dark green)	~15%
(blue)	~7.5%



Hood Capture Velocities

Equal Velocity Zones

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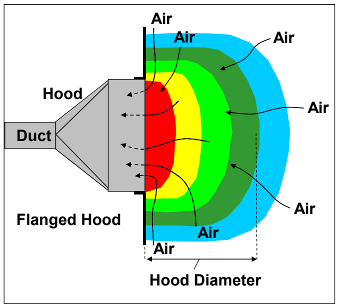
(light blue)	~7.5%

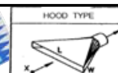
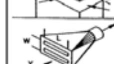
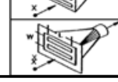


Recommended Capture Velocities

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

Design Duct Velocities

CONTAMINANT	EXAMPLES	DESIGN VELOCITY (fpm, m/s)
Vapors, gases, smoke	Vapors, gases, smoke	1000 – 2000, 5.0 – 10.1
Fumes	Welding	2000 – 2500, 10.1 – 12.7
Very fine dust	Cotton lint	2500 - 3000, 12.7 – 15.2
Dry dusts & powders	Cotton dust	3000 - 4000, 15.2 – 20.3
Industrial dust	Grinding dust, limestone dust	3500 - 4000 , 17.8 – 20.3
Heavy dust	Sawdust, metal turnings	4000 - 4500, 20.3 – 22.9
Heavy/moist dusts	Lead dusts, cement dust	> 4500, > 22.9

HOOD TYPE	DESCRIPTION	ASPECT RATIO, W/L	AIR FLOW
	SLOT	0.2 OR LESS	Q = 3.7 LVX
	FLANGED SLOT	0.2 OR LESS	Q = 2.6 LVX
	PLAIN OPENING	0.2 OR GREATER AND ROUND	$Q = V(10X^2 + A)$
	FLANGED OPENING	0.2 OR GREATER AND ROUND	$Q = 0.75V(10X^2 + A)$
	BOOTH	TO SUIT WORK	Q = VA = VWH
	CANOPY	TO SUIT WORK	Q = 1.4 PVD SEE FIG. VS-99-03 P = PERIMETER D = HEIGHT ABOVE WORK
	PLAIN MULTIPLE SLOT OPENING 2 OR MORE SLOTS	0.2 OR GREATER	$Q = V(10X^2 + A)$
	FLANGED MULTIPLE SLOT OPENING 2 OR MORE SLOTS	0.2 OR GREATER	$Q = 0.75V(10X^2 + A)$

Capture Velocity

- Plain End Opening — $Q = v(10X^2 + A)$
- Flanged Opening — $Q = 0.75v(10X^2 + A)$
- Slot — $Q = 3.7\ LvX$
- Flanged Slot — $Q = 2.6\ LvX$
- Booth — $Q = vWH$
- Canopy — $Q = 1.4\ PvX$

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

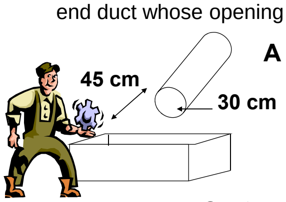
Hood Type Calculations

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

Q = Quantity of air (m^3/s)
v = Velocity of air (m/s)
X = Distance from hood face to point of contaminant generation (m)
A = Area (m^2)

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.



$$A = \frac{\pi\ (30\ cm/100)^2}{4} = 0.071 m^2$$

$$Q = v\ (10X^2 + A)$$

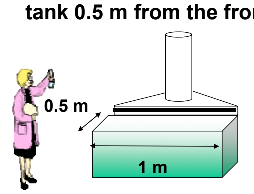
Assume a capture velocity = 0.5 m/s

$$Q = 0.5\ m/s\ [(10 \times 0.45^2) + 0.071\ m^2]$$

$$Q = 0.5\ m/s\ (2.096\ m^2) = 1.048\ m^3/s$$

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.



Assume a capture velocity of 0.5 m/s

$$Q = 2.6LvX$$

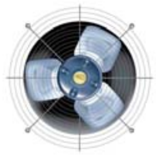
$$Q = 2.6(1\ m)(0.5\ m/s)(0.5\ m)$$

$$Q = 0.65\ m^3/s$$

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 m^3/s of air running at 400 RPM. If fan speed increases by 25% to 500 RPM, what is the <u>new air flow</u>?



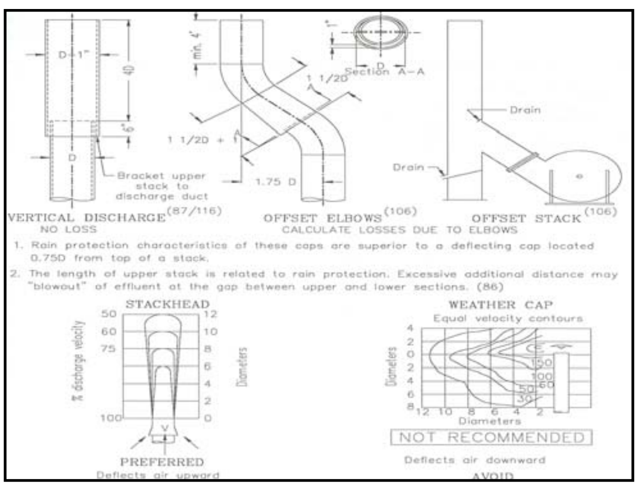
$$Q \propto RPM$$

$$Q_2 = Q_1\left(\frac{RPM_2}{RPM_1}\right)$$

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

Hood Exhaust

- **Height**
- **Discharge velocity**
- **Configuration**



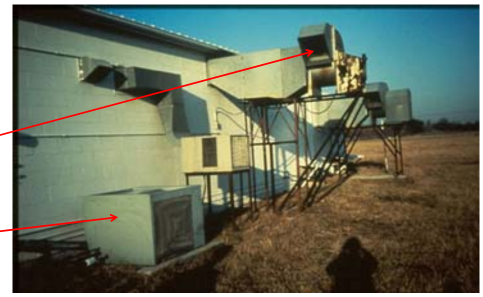
Engineering Controls: Avoid Exhaust Recirculation

Hood Exhaust

Air Intake

Engineering Controls: Avoid Exhaust Recirculation

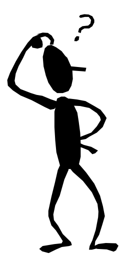
High Hazard Hood Exhaust



Air Intake

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**
- **Ray Ryan, Flow Sciences International, Leland NC, USA http://www.flowsciences.com**

Any Questions?

Laboratory Chemical Hoods:

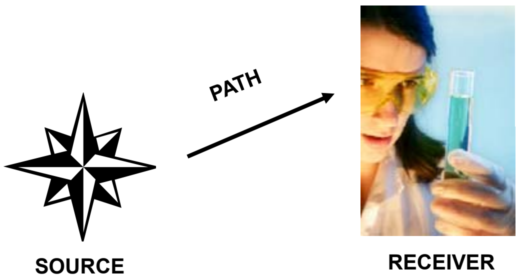
How they work & when they don't.

Improper Hood Use

Laboratory Chemical Hood

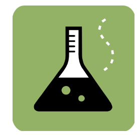
- **Also called a fume hood or fume cupboard**
- **Designed to limit exposure to hazardous or unpleasant aerosols**
- **First used by alchemists 500 years ago**

Control Concept



LEV Objectives

- Maximize Containment
- Minimize Contamination
- Redundancy is the Key

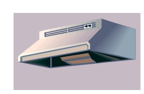


LEV Implementation

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

LEV Capture Ability

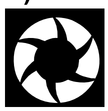
- Hood configuration (type of hood)



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

Duct Design

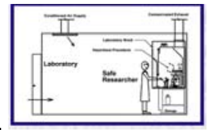
- Provide adequate capture velocity
  - Usually 80-120 fpm (0.4 - 0.6 m/s)



- Maintain duct transport velocity
  - For chemical laboratories ~ 2500 cfm (1.2 m^3/s)

Duct Design, cont'd.

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



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

http://www.clf.rl.ac.uk/facilities/AstraWeb/images/Photo7/Air_duct_TA3.JPG

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

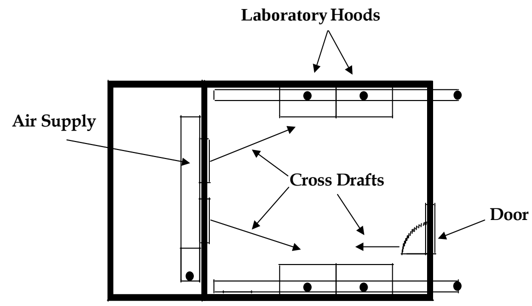
Laboratory hoods and ventilation are the basis of engineering controls.

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

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

http://www.news.harvard.edu/gazette/daily/0403/photos/03-meltonstem_1.jpg

Hood Design & Operation, cont'd.

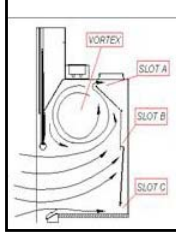
- Work in the center of hood and 15 cm in from hood sash.
- Don't store chemicals or equipment in hood.
- Don't block baffles (slots).
- Maintain hood regularly (check fan belt, lubricate motor).
- Regularly evaluate hood (flow rate, mark operating sash height).
- Reports problems, concerns, malfunctions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

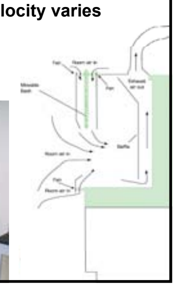
Laboratory Hood Types

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

Traditional Constant Volume Hood

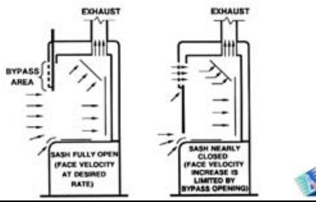
- All make up air enters through hood face.
- Air exhausted is constant regardless of size of face opening or sash height.
- Volume of air movement is constant but velocity varies with sash height.





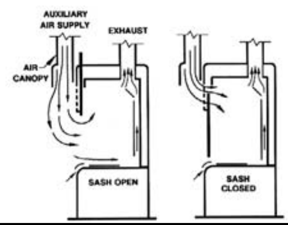
Constant Volume Bypass Hood

- 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.

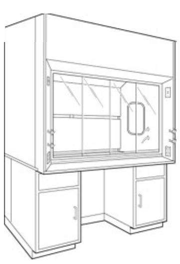


* According to ANSI Z9.5

HOPEC Hood
(Hand Operated Positive Energy Control)

Combination Horizontal/vertical sash limits sash opening to no more that 50%.

Maintains constant air volume and limits energy consumption.

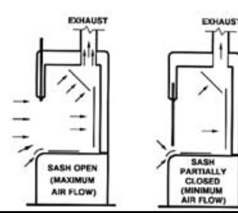


Variable Air Volume (VAV) Hood

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)

Specialized Hoods

ADA Hood

Glove Box

Canopy Hood

Floor Hood

Laboratory Ventilation

Example: Typical Walk-In Fume Hood

Laboratory Ventilation

EXAMPLE: "Snorkel" Fume Extractor

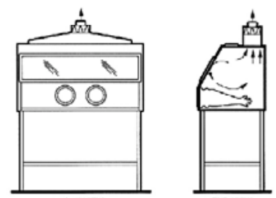
Extracting Lead Solder Fumes

Example: Canopy Hood

Laboratory Ventilation

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.

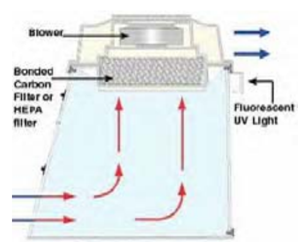


Special purpose vented hood

Chemical weighing station

Bulk powder transfer station

Ductless Hoods



Ductless Hoods

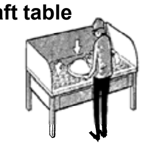
Should only be used in laboratories with:

- 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.

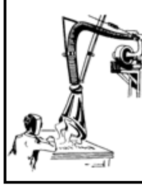
Specialized Hoods

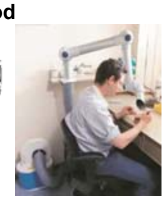
Dust hood, Animal feed

Downdraft table

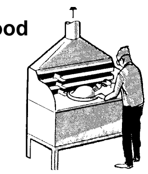


Snorkel hood





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.

Reference: http://www.cdc.gov/od/ohs/biosfty/bsc/bsc.htm

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 (SF_6)
- 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

Ventilation System Evaluation

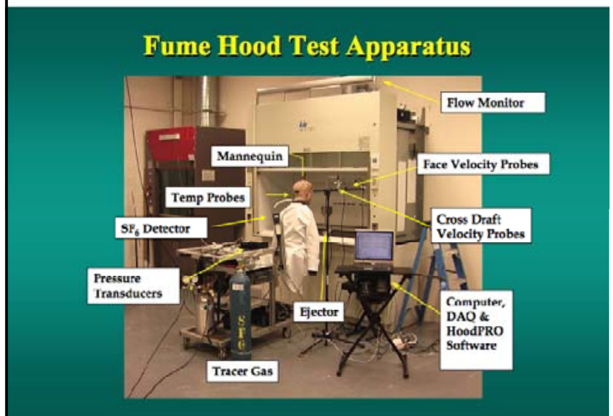
- Velocity measurements
  - Anemometer/velometer
    - fpm or m/s
    - Directional
  - Hot-wire anemometer
    - fpm or m/s
    - Non-directional

Hood Smoke Evaluation
Face velocity *vs.* Containment

- **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 SF_6 as a tracer gas
- SF_6 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

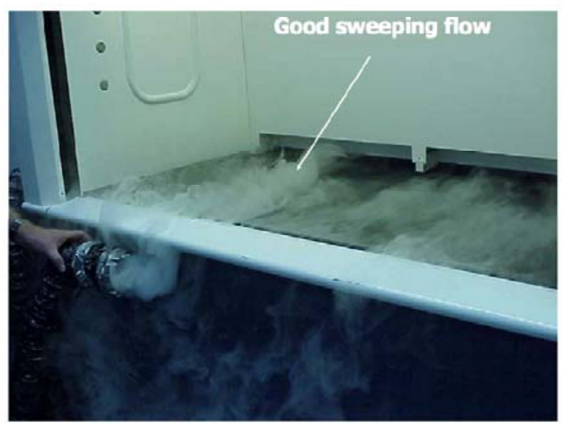


Gas Cylinder Inside Hood

Hood Loading Challenge Test

Walk-By Challenge Test

Cross Draft Challenge Tests



Conclusions

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

Acknowledgements

- Tom Smith ECT, Inc., Cary NC USA
- University of North Carolina, Chapel Hill NC USA
- Texas A & M University
- Flow Sciences Inc, Leland NC USA
- Knutson Ventilation, Edina MN USA
- AirClean Inc, Raleigh NC USA

LUNCH

Chemical Management

Best Practices

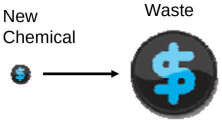
Cradle - to - grave care of chemicals

Receipt → **Storage** →

Use → **Disposal**

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

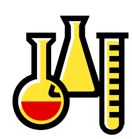
- **Reduces hazardous waste**
- **Reduces cost**
  - **New purchases**
  - **Waste disposal**
  - **More efficient**
- **Improves security**
  - **Insider threat**
  - **Outsider threat**
- **Facilitates environmental compliance**
- **Improves quality of research**
- **Improves quality of lab instruction**



Proper chemical management program has several essential elements

Chemical Management 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

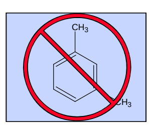
Less is Better !

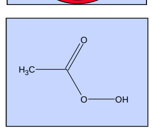
- Order only what you need
- Reduce size of experiment
  - It cost less to store
  - It cost less to dispose

"Less is Better: Guide to minimizing waste in laboratories", Task Force on Laboratory Environment, Health and Safety, American Chemical Society, 2002. http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_SUPERARTICLE&node_id=2230&use_sec=false&sec_url_var=region1&__uuid=ef91c89e-8b83-43e6-bcd0-ff5b9ca0ca33

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

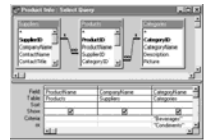
- See if your institution already has it (surplus)
- Order minimum needed (large quantities are not a bargain)
- Check on special storage (refrigeration, dry box…)
- Mark the receipt /open date (unstable chemical)
- Can it eventually be disposed of (rad waste, mixed waste)

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

BARCODE	LOCATION	DEPT	QUANTITY	UNIT	Purchase Date
AQ00600682	NM/518/1111	1725	1	L	10/24/2006
AQ00602185	NM/518/1123	1111	100	mL	11/20/2006
AQ00582298	NM/518/1302	1131	1	L	8/8/2006
AQ00602186	NM/518/1302	1131	100	mL	11/20/2006
AQ00602187	NM/518/1302	1131	100	mL	11/20/2006
AQ00582307	NM/518/1302	1131	4	L	8/8/2006

(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

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

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, LAlH, flammable metals

Control measures:

- Inventory control
- SOPs, inspections

Inventory management

-R-O-O-R-

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

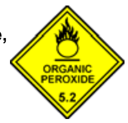
- Peroxide formation is caused by an autoxidation reaction.
- The reaction is initiated by light, heat, introduction of a contaminant or the loss of an inhibitor (BHT).
- Inhibitors slow, but do not stop peroxide formation.
- Most organic peroxide crystals are sensitive to heat, shock, or friction.
- 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



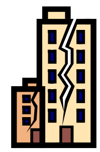
References:

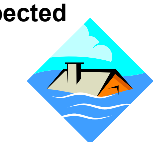
There are excellent websites on peroxide forming chemicals and their hazards, use, storage, and disposal. For example, see:

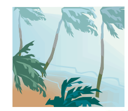
http://www.med.cornell.edu/ehs/updates/peroxide_formers.htm

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


Compressed Gas Cylinders

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

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


Improper gas cylinder storage

Damage from Gas-cylinder fire

An Accident Waiting to Happen

CSB video: Compressed gas fire

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 ¾” 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!!!

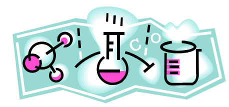
Chemical storage: Good practices

- **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

From: "School Chemistry Laboratory Safety Guide," US NIOSH Publication 2007-107



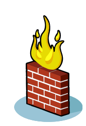
Suggested shelf storage groups: Inorganics

- 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

From: "School Chemistry Laboratory Safety Guide," US NIOSH Publication 2007-107

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/acs/corg/content?_nfpb=true&_pageLabel=PP_SUPERARTICLE&node_id=2230&use_sec=false&sec_url_var=region1&__uuid=ef91c89e-8b83-43e6-bcd0-ff5b9ca0ca33

"School Chemistry Laboratory Safety Guide," US NIOSH Publication 2007-107, Cincinnati, OH, 2006, available on-line:
http://www.cpsc.gov/CPSCPUB/PUBS/NIOSH2007107.pdf

"Prudent Practices in the Laboratory: Handling and Disposal of Chemicals," National Academy Press, 1995, available online:
http://www.nap.edu/catalog.php?record_id=4911

BREAK

Other Hazards in a Chemical Laboratory

Physical Hazards

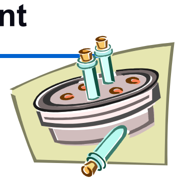
Conditions, besides chemical, biological or radiological conditions or circumstances, that can cause injury, illness and death:

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

Asbestos-Containing Materials

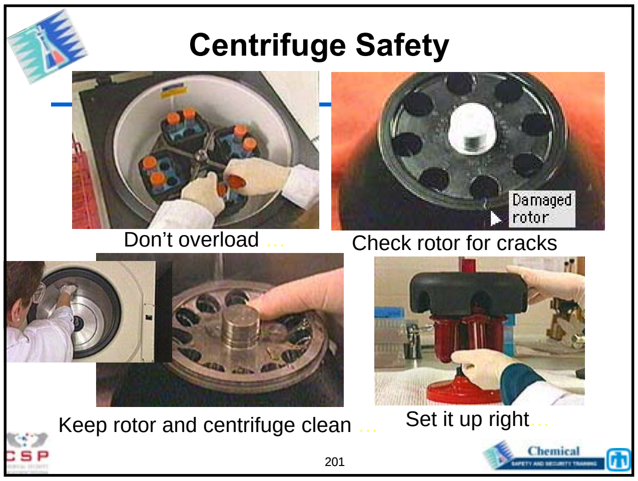
- Gloves
- Lab hoods
- Lab benches

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
Damaged rotor
Don't overload …
Check rotor for cracks
Keep rotor and centrifuge clean …
Set it up right…
CSP
201
Chemical

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.

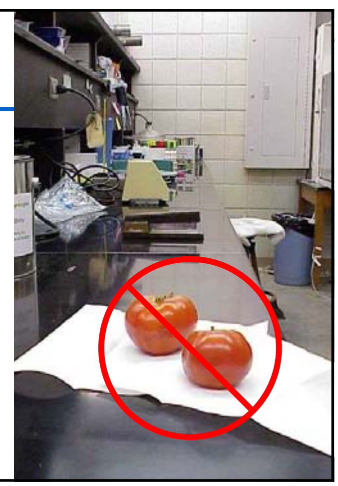
Safety shields can block airflow and reduce hood effectiveness.

Don't block hallways and exits!

Access to emergency equipment is essential.

Always check that equipment is not blocked.

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.

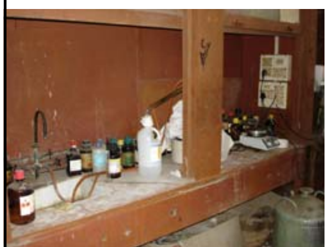
Working Alone/Unattended Operations

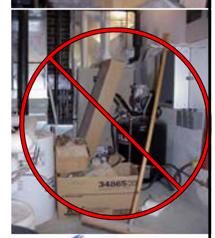
- Working Alone
  - *Avoid!*
  - Murphy's Law will get you! (Anything that can go wrong, will go wrong!)
  - Use the "Buddy System"
- Unattended Operations/Reactions
  - Caution! Prime sources of fires, spills and explosions
  - Check periodically!
  - Fail-safe provisions
  - Leave the lights on to 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.

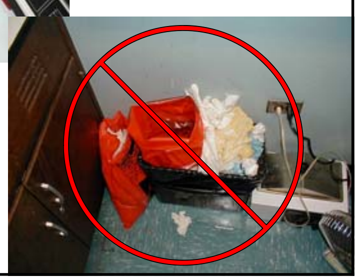




Storage should be at least 1 m from electrical panels, mechanical rooms, air ducts, heaters, light fixtures.

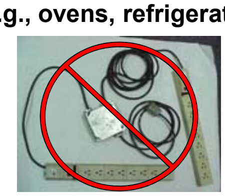
Don't store combustibles in mechanical rooms or electrical closets.

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



Multi-outlet strips must be approved and <u>not</u> used for high-amp equipment.

(e.g., ovens, refrigerators)



Don't Do This…

Heating Mantles

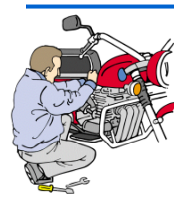
- Uses
- Hazards
- Unshielded rheostats
- Control measures

Ergonomics

- Types of hazards

- Why be concerned with Ergonomics?

Awkward Posture

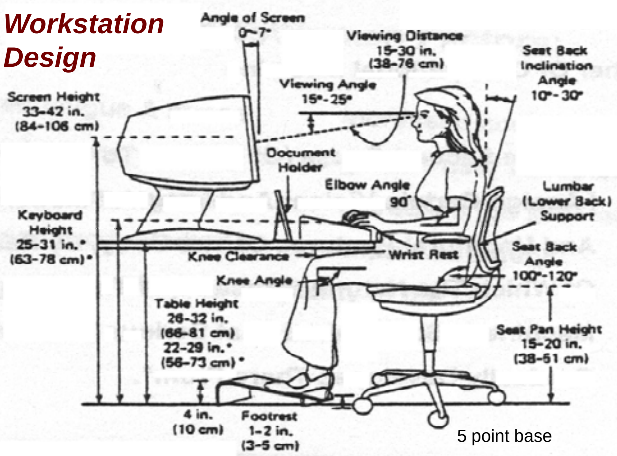


Too low

Too far away

Too high

Workstation Design



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.

Disorder	Affected Site
Carpal Tunnel Syndrome	Wrist
Tendonitis	Elbow, wrist, hand
Tenosynovitis	Elbow, wrist, hand
Epicondylitis	Tennis elbow
Reynaud's phenomenon	"White finger"
Ulnar neuropathy	Fingers

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!

Autoclave Explosion

High Pressure Reactions

- Experiments carried out at pressures above 1 atmosphere (~1bar, 760 Torr, ~100,000 Pa).
  - Use of supercritical fluids (CO_2)
- 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

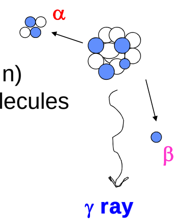
- Elevated noise levels can be a problem.
- Potential Hazards
  - Examples: bone-cutting saws, mechanical water aspirators, sonicators, pumps.
- Control Measures
  - Inspections, PPE, warning labels, training.

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



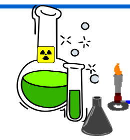
- **NON-IONIZING RADIATION**
  - Electromagnetic (UV, IR, MW, RF)
  - Can not ionize atoms or molecules

Common Uses of Ionizing Radiation

Research & Development

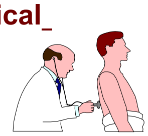
$^{14}_{6}C$ $^{35}_{16}S$ $^{3}_{1}H$

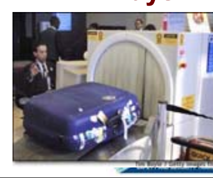
$^{125}_{53}I$ $^{32}_{15}P$




X-Rays

Medical



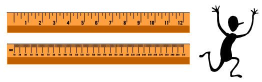
Electron Microscopes

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

Protect yourself by:

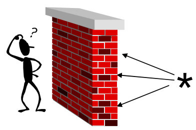
- **TIME** – Limit time near source

- **DISTANCE** – Stay away

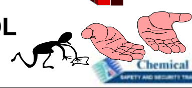


$$I_2 = I_1\left(\frac{d_1}{d_2}\right)^2$$

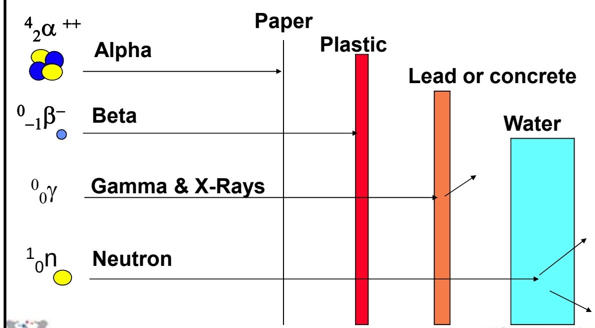
- **SHIELDING** – Absorb energy



- **CONTAMINATION CONTROL**



Shielding Materials



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

Robotics

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