Brookhaven National Laboratory

Exhaust Ventilation Handbook

Table of Contents

Topic	Page
Preamble	2
Safe Work Practices for Laboratory Hood Use by Workers	3
General Principles of Design and Use	5
Intake Design	8
Ducting and Fan Design	13
Air Cleaning Technology (including HEPA Filtration)	16
Discharge Design	21
Perchloric Acid Hoods and Exhaust Systems	24

Preamble

Scope of the BNL Exhaust Ventilation Handbook

The object of exhaust ventilation is to control worker exposure to toxic airborne hazards in a safe, reliable manner.

- This handbook provides guidance on the design and operation of new and existing exhaust ventilation systems.
- When a passage is specifically cited in the Exhaust Ventilation Subject Area, the applicable text in this document is mandatory.
- **New systems should be designed to meet the guidance described in this document. In addition, new systems are to be installed within manufacturer's installation specifications.**
- **Existing equipment should be upgraded or replaced if its current design is not capable of providing exposure control and environmental protection at regulatory acceptable levels.**

Ventilation (air moving) systems can be divided into two major classes:

- HVAC - Heating, Ventilation (nontoxic) and Air Conditioning systems;
- Hazard Control systems (exhaust ventilation).

This handbook deals with *Hazard Control Exhaust Ventilation Systems* design and use. Not covered in this handbook are

- Product Integrity systems;
- Clean Room systems.

The format of the sections includes passages on

- **General Principles:** A section with information provided for knowledge and understanding of those planning, designing, using, testing, and/or maintaining *Hazard Control Exhaust Ventilation Systems.*

- **Criteria for design, use, testing and maintenance:** A section with requirements and best management practices for successfully implementing hazard control by exhaust ventilation. This handbook establishes general design criteria for new or modified exhaust systems. It is not intended to limit exhaust system design to these specifications when issues such as energy conservation measures, unique application, or specific structure or terrain geometry render these general criteria less than optimum.

This document provides principles and general guidance meant to aid in compliance with the following requirements:

- 10 CFR 835, Occupational Radiation Protection
- 29 CFR 1910.94, Occupational Safety and Health Standards (OSHA), Ventilation
- 29 CFR 1926.57, Safety and Health Regulations for Construction, Ventilation
- 40 CFR 61, National Emission Standards for Hazardous Air Pollutants
- DOE Order 440.1A, Worker Protection Management for DOE Federal and Contractor Employees

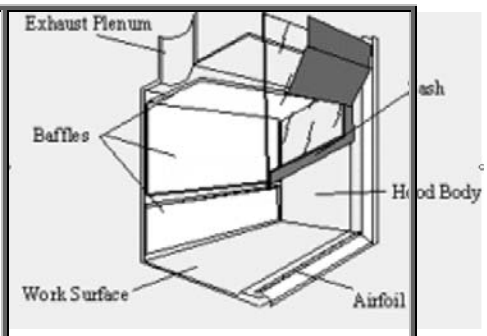
For specific details on the design and optimization of exhaust systems, the following references should be consulted:

- ACGIH, *Industrial Ventilation: A Manual of Recommended Practice*
- ANSI Z9.2, *Fundamentals Governing the Design and Operation of Local Exhaust Ventilation Systems*
- ANSI/AIHA Z9.4, *Abrasive-Blasting Operations - Ventilation and Safe Practices for Fixed Location Enclosures*
- ANSI/AIHA Z9.5, *Standard for Laboratory Ventilation*
- ANSI/AIHA Z9.6, *Exhaust Systems for Grinding, Polishing, and Buffing*
- ANSI AWS F3.2, *Ventilation Guide for Weld Fume*
- ANSI/ASME N509, *Nuclear Power Plant Air-Cleaning Units and Components*
- ANSI/ASME N510, *Testing of Nuclear Air Treatment Systems*
- ANSI/ASHRAE 62, *Ventilation for Acceptable Indoor Air Quality*

Safe Work Practices for Laboratory Hood Use by Workers

Basic features of a typical laboratory hood

- **Exhaust Plenum** - carries air from point of collection
- **Sash** - adjusts the opening to the hood face
- **Baffles** - panels that create the point of entry of air into the duct system
- **Airfoil** - a slot at the front of the hood that ensures a portion of the air enters the hood and sweeps the surface of the interior of the hood.

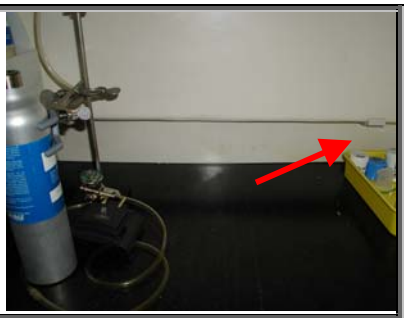
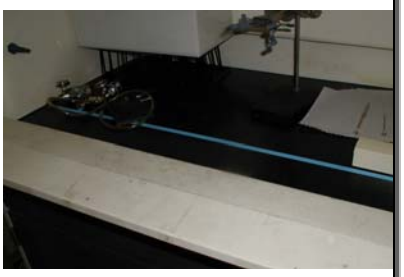


Essential Do's and Don'ts for laboratory hood work

1. **Do <u>not</u>** *store* large numbers of chemical containers or equipment in hood. The containers can block the air intake or unbalance the distribution of air. Place chemical containers into a lab hood only when they are to be used.

2. **Do** store very hazardous chemicals in appropriate storage units such as flammable cabinets and corrosive cabinets and store low to moderate hazard chemicals on shelves and in cabinet.

   Use a lab hood to store only very small quantities of very odorous chemicals (like mercaptans) or extremely hazardous gases (like nickel carbonyl). When storing chemicals in a hood, use a non-flammable shelf or metal rack to elevate the container off of the working surfaces so that the baffles are not blocked. **Do not** place containers within 6 inches of the hood face.

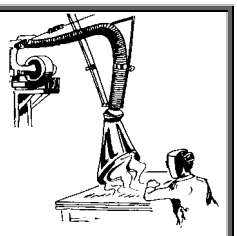
3. **Do** keep the rear baffle area (slots) clear of equipment to allow air to flow into the hood evenly across the whole work surface area.	
4. **Do <u>not</u>** store large pieces of equipment near the front of a hood. This may cause the entering air to bounce back into the room and carry some contaminants from inside the hood into the room. Keep all apparatus at least 6 inches (15 cm) back from the face of the hood. A strip on the bench surface is a good reminder. Large pieces of equipment should be raised to allow airflow under and around the equipment to minimize airflow problems.	
5. **Do <u>not</u>** open "sash hoods" beyond the point indicated on the "face velocity test" sticker. Opening the sash higher may result in insufficient air velocity going into the hood to contain all contaminants.	
6. **Do** have your lab hood tested for "face velocity" annually. Periodically check the date on the sticker to make sure it has been tested within the last year. Significant changes to the setup of equipment in the hood can change the airflow pattern and may result in the need to have a new *face velocity test*.	
7. **Do** use the sash as a barrier during hazardous operations and during work where projectiles may occur. Ensure that the sash is not lowered so far as to interfere with safely doing work within the hood.	
8. Do <u>not</u> put your head in the hood when contaminants are being generated.	
9. **Do** minimize foot traffic past the face of the hood. Walking past a hood at a normal pace (3 mph) can create a current that exceeds the inward velocity produced by the hood fan. Do not locate hoods near frequently used doors.	
10. Do use a flow indicator, such as a tissue strip hung from the sash, to verify that the system is operational.	

General Principles of Design and Use

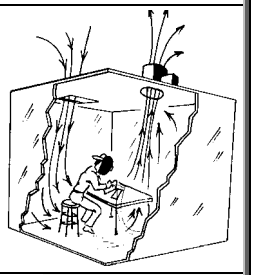
General Principles of Exhaust Ventilation

1. The three major classes of **exhaust systems** are

- ***Local Exhaust Ventilation (LEV) systems***: Units that collect of toxic materials before they can be released into the breathing zone of the workers. This is the preferred design as it eliminates most of the hazard from reaching the worker. Examples are lab hoods, glove boxes, and "elephant trunk" fume extractors.



- ***General Exhaust Ventilation (GEV) systems*** (dilution ventilation): Units that allow the release of the contaminants into the breathing air. A large volume of air passes into the breathing zone to "dilute" the concentration of the offensive material to acceptable levels. Examples of proper use of these systems are: bathroom fans, roof fans, and wall louver fans. This type of system is also appropriate for use for heat or humidity control.



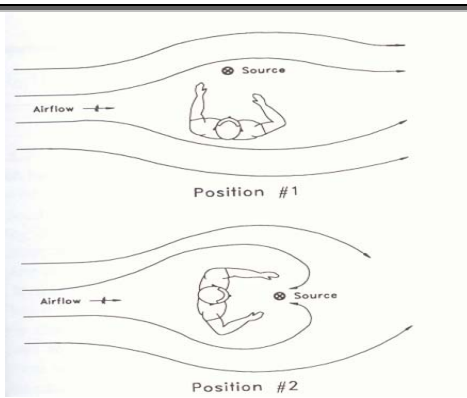
- ***Filtered Vacuum Cleaners:*** Units used to eliminate a *radiological* or *chemical* hazard from surfaces. They do not provide protection from the initial release of hazards. They are used to protect the worker, work area occupants and the environment during clean-up operations.

2. BNL categorizes exhaust ventilation systems based on the application and hazards as follows

- ***Worker Hazard & Pollution Control:*** Unit that protects the environment and/or worker from nuclear, radiological, chemical hazards:
  - ***Nuclear:*** A unit that protects the environment and worker in a DOE Nuclear Category 1, 2, or 3 facility
  - ***Non-Nuclear:*** A unit that protects the environment or worker for
    - National Emission Standards for Hazardous Air Pollutants (NESHAPS) when environmental release levels exceed EPA NESHAPs limits;
    - **Radiological hazards** below the *Nuclear* level; or
    - **Chemical hazards** used to keep occupational exposure level from exceeding Occupational Exposure Limits or when ventilation control is relied on in lieu of chemical specific hazard exposure assessments.
- ***Product Integrity:*** A unit used for applications other than worker and environmental protection.

3. **The Design Principles and Criteria listed in this handbook apply only to *Hazard & Pollution Control* applications.**

Significant characteristics of contaminants that affect exhaust ventilation

1.	Contaminants with specific gravity that is “heavier” or “lighter” than air are not subject to appreciable motion up or down based on their own density. Only in very hot or very cold operations (thermal buoyancy) or where contaminants are released in very high concentration will movement occur based on density.
2.	Gases, vapors, fumes, and fine dust (<20 microns in diameter) will not exhibit significant inertial effects. These materials will move solely with respect to the air in which they are mixed and the velocity at which they are discharged if pressurized. Exhaust systems (including hoods) need to generate velocity sufficient to control the motion of contamination laden air plus extraneous air currents caused by drafts and movements nearby.
3.	As air flows around an object, a turbulent wake on the downstream side occurs. This wake region has significant mixing and recirculation. A human body can create a wake, so hazardous operations need to be performed in a manner to prevent contaminants from circulating into the breathing zone • A 90° orientation to the airflow works well (see Position #1). • A 180° orientation to the airflow with the back to the wind direction works creates a zone where contaminants can be pulled into the worker breathing area (see Position #2). 

Criteria for design, use, test, and maintenance

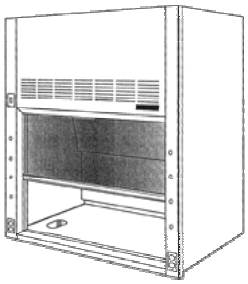
1.	Air exhausted from laboratory hoods and other local exhaust systems is not to be re-circulated into a HVAC system. Air exhausted from areas where chemicals are used is not to be passed un-ducted through other areas.
2.	Laboratories, and areas where hazardous chemicals are used, need to be maintained at a negative air pressure with respect to corridors and adjacent non-lab and non-chemical use areas.
3.	Mechanical ventilation systems needs to remain on at all times when hazardous substances are in use and for a sufficient time after to clear hoods or the area of airborne hazardous substances. When mechanical ventilation is not in operation, hazardous substances need to be covered or capped off.
4.	For systems to operate effectively, adequate replacement air (make-up air) must be supplied. For occupant comfort, the replacement air needs to be tempered to the room temperature. The exhaust system should NOT be relied on to pull replacement air into the building. If adequate replacement air is not provided, the exhaust system will operate at less than the design flow rate and the area will be under negative pressure. In most cases, the replacement air flow rate should approximately the same as the total air flow rate removed by the exhaust ventilation system, process systems, and combustion processes.
5.	Take into account, any planned expansion of processes, and design the system slightly larger than is immediately necessary.

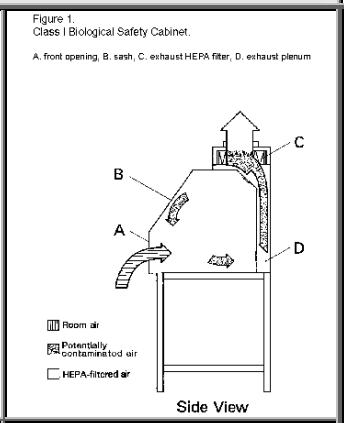
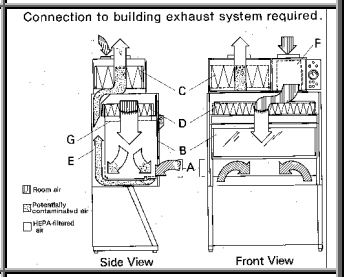
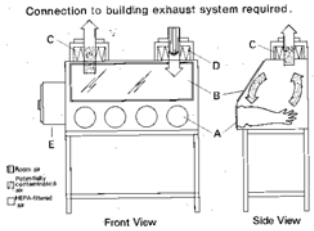
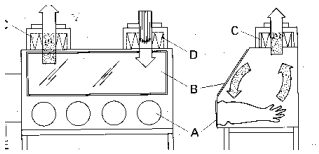
6.	**Air Changes:** The "air change per hour" used in occupant comfort HVAC situations, is a poor criteria for ventilation of hazards, heat, or odors. Ventilation depends on the source rate of generation, not the size of the room.
7.	**Dilution ventilation system:** When low toxicity chemicals at low concentrations that are not in excess of occupational exposure limits are to be controlled with dilution ventilation to at least the ANSI/ASHRAE 62 recommended 20 cfm per person (in spaces of seven persons per 1000 ft^2).
8.	**Acceptance Testing:** All ventilation systems need to be tested at the time of initial installation to verify the volumetric flow rates and pressure levels. The appropriate tests need to be made per techniques described in the ACGIH, *Industrial Ventilation: A Manual of Recommended Practice* for: • Static pressure; • Velocity pressure; • Volumetric flow; • Air velocity; • Differential pressure across newly installed air filters; • System balance on branched ducting;
9.	**Periodic Testing:** For existing installations, routine retesting of the acceptance test criteria is not typically necessary. Systems need to be retested if • Process is significantly changed; • System components (hoods, enclosures, ducting, etc.) are modified. Some tests are routinely conducted to verify the continued performance of equipment, including • Laboratory Hood Face Velocity Testing; • HEPA Filter penetration surveillance testing; • Adsorber capacity testing/monitoring; • Differential pressure across installed air filters.

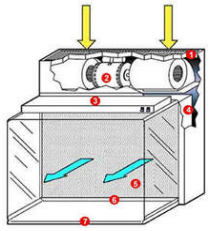
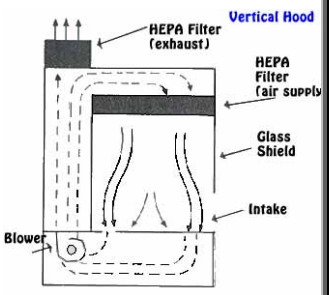
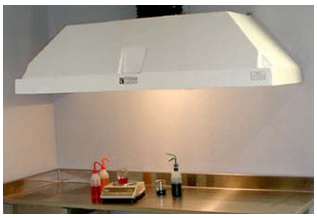
Intake Design

Principles of Intake Design

Two basic designs for the intake to exhaust ventilation systems are: 1. **Capture (or exterior):** The hazard is generated and released outside of the intake device. Air movement into the intake device draws the hazard into the system. Examples are "elephant trunk" fume extractors.	
2. **Containment (or enclosing):** The hazard is released inside the intake device and the airflow pattern "contains" the hazard from entering the worker breathing zone. Examples are laboratory hoods and glove boxes.	

Major types of intake designs		
Design Type	Principle of Design - Key Features, Precautions	
Lab hood	Containment: A moveable sash is raised to place objects into the hood, and lowered when work is being done. The sash also serves as a safety barrier. Air moves into the hood, across the interior and exits through opening typically at the back and top of the hood.	
Re-circulating hoods	Containment: Same as lab hood usually with a moveable sash. Air moves into the hood, across the interior but is recycled back into the room after passing through appropriate air cleaning media (such as filters and activated carbon). Often these units have a built-in monitoring device to indicate when the adsorbent is full.	
Fume adsorber	A fume adsorber uses media, like activated carbon, to adsorb vapors. Vapors are trapped in the adsorbent filter while the cleaned air is recirculated into the room. It requires no ducting to the outside and is portable. The filter may hold 20 to 50 of its weight in vapors.	

Major types of intake designs		
Design Type	Principle of Design - Key Features, Precautions	
Biosafety Cabinet, Class I	The *Class I Biosafety Cabinet* is a negative-pressure, ventilated cabinet usually operated with an open front and a minimum face velocity at the work opening of at least 75 feet per minute (fpm). All of the air from the cabinet is exhausted through a HEPA filter either into the laboratory or to the outside. It is designed for general microbiological research with low- and moderate-risk agents. These cabinets are *not* appropriate for handling research materials that are vulnerable to airborne contamination, since the inward flow of unfiltered air from the laboratory can carry microbial contaminants into the cabinet.	
Biosafety Cabinet, Class II, Type B	*The Class II, Type B Biosafety Cabinet* is hard-ducted to an exhaust system and contains negative pressure plena. These features, plus a face velocity of 100 fpm, allow work to be done with toxic chemicals or radionuclides.	
Biosafety Cabinet, Class III	The *Class III Biosafety Cabinet* is a totally enclosed, ventilated cabinet of gas-tight construction and offers the highest degree of personnel and environmental protection from infectious aerosols, as well as protection of research materials from microbiological contaminants. Class III cabinets are most suitable for work with hazardous agents that require Biosafety Level 3 or 4 containment. All operations in the work area of the cabinet are performed through attached arm length rubber gloves or half-suits. The Class III cabinet is operated under negative pressure. Supply air is HEPA-filtered and the cabinet exhaust air is filtered through two HEPA filters in series, or HEPA filtration followed by incineration, before discharge outside of the facility.	
Glove box	A glove box is a totally enclosed, ventilated cabinet of gas-tight construction and offers the highest degree of personnel protection. Operations in the cabinet are performed through attached arm length rubber gloves.	
Hot cell, hot box	A hot box is an enclosed, ventilated cabinet with radiological shielding for personnel protection. Operations in the cabinet are performed through articulated arms.	

Major types of intake designs		
Design Type	Principle of Design - Key Features, Precautions	
Clean benches, horizontal or vertical laminar flow	*Horizontal or vertical laminar flow "clean benches"* are used in clinical, pharmaceutical, and laboratory facilities strictly for *product* protection. **This equipment must *never* be used for handling toxic, infectious, radioactive, or sensitizing materials,** since the worker sits in the immediate downstream exhaust from the "clean bench."	
Exhausting laminar flow hood	*Exhausting laminar flow hood* produce a “curtain of air” at the face of the unit and may be useful for certain manipulations of clean materials (e.g., pouring agar plats) but should not be used when working with infectious materials. These units are vented. **Unless the interior of the hood is vented out of the room or appropriately filtered and the unit operates at negative pressure, this equipment must *never* be used for handling toxic, infectious, radioactive, or sensitizing materials.**	
Walk-in hoods	*Walk-in hoods* have a face opening extended to the floor level to accommodate large objects. They are not intended for the user to be inside the hood while performing work. This type of hood operates best with the sash opening partially closed. The hood is suited for operations where tall apparatus is used and equipment is rolled into the work area.	
Perchloric acid hood	A *perchloric acid hood* is designed specifically for use with perchloric acid and metallic perchlorates. The hood has a stainless steel or PVC interior with washdown system and water collection trough. **See the section in this handbook on Design and Criteria for Perchloric Acid Hoods.**	
Canopy hoods	A *canopy hood* is designed to vent non-toxic materials such as heat, steam and odors from large or bulky apparatus such as ovens, steam baths and autoclaves, wall-mounted or suspended from the ceiling. The design that relies primarily on exhaust heat or gas density to carry contaminant and odors into the capture zone of the hood suspended over the work area.	

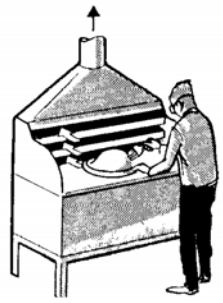
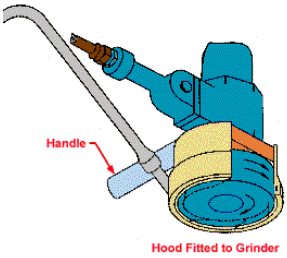
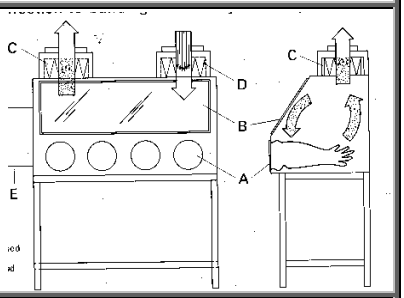
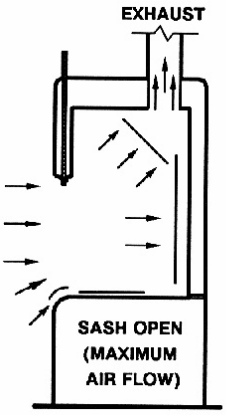
Major types of intake designs		
Design Type	Principle of Design - Key Features, Precautions	
Tank slot capture systems	Contaminants are captured near the source by a flow of air that sweeps across the face of a tank or worktable and enters the ductwork at a point away from the worker breathing zone.	
Spray booth	A large walk-in enclosure. The spray operation is done within the enclosure and vents the paint spray laden air, through filters to an exhaust fan. Because the worker typically enters the enclosure during spraying, this is NOT considered a local exhaust system. When hazardous paints are used, the worker must use personal protective equipment. The system does function as a general dilution and housekeeping system to help keep the balance of the facility at safe levels of paint and free of overspray residues.	
Point of release tool controls, extractors	Specifically designed "heads" or shrouds for a tool to capture the hazardous substance at the point of generation. It may be used on portable and fixed grinders, buffers, drills, saws, etc. See table 1 on capture velocities need for control.	
Local exhaust capture, fume extractors	An extractor arm captures the contaminants at the source. Once in position, the arm and its inward airflow pulls the air into the extractor to keep the air clean in the workspace. See table 1 on capture velocities needed for control.	

Table 1: Examples of *Capture Velocity* at point of capture needed to control hazards

Dispersion of hazards	Example	Capture Velocity (fpm)
Practically no velocity, into quiet air	Tank evaporation	50-100
Low velocity into moderately still air	Spray booth	100-200
Active generation into rapid air motion	Convey loading	200-500
High velocity into very rapid air motion	Grinding	500-2000

Criteria for design, use, test, and maintenance

1.	When flammable gases or liquids are used, exhaust systems and hoods (that do not have a duct bypass) need to have permanent stops installed to restrict closure of the sash so that sufficient airflow is maintained. This will prevent explosions by maintaining the dilution of the concentration below flammable levels. The concentrations in the duct are not to exceed 20% of the lower explosive limits.
2.	Use *glove boxes* for highly toxic radiological, chemical, and biological materials. Provide exhaust from the glove box of 35 to 50 cubic feet per minute. When working with highly reactive chemicals, use an inert atmosphere in the glove box. 
3.	**Laboratory-type hoods** need to provide confinement of the hazard(s) and protection of the employees based on: • The face velocity needs to be sufficient to maintain an inward flow of air at all openings into the hood. • The system needs to provide an average face velocity of at least **100** feet per minute with a minimum of **80** feet per minute at any point. • If the enclosure is not completely around the source, avoid a velocity above 125 fpm to prevent eddies that may pull the hazard toward the operator. • The face velocity needs to be obtainable with movable sashes fully opened. Where the minimum velocity can only be obtained by partly closing the sash, mark the sash and/or jamb to show the maximum opening at which the hood face velocity meets the requirements. Never operate the hood with the sash opening exceeding the marking. • Where more or less stringent requirements are needed do to unusual circumstances or hazards, the SME can prescribe different criteria. • Annual testing of the face velocity is required, unless otherwise stated in the *BNL Exhaust Ventilation Design Specifications and Use Agreement* for the equipment. 

Ducting and Fan Design

Principles of Ducting and Fan Design

1.

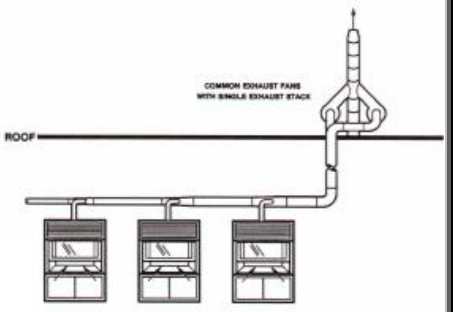
Loss of total pressure in ducts occurs from two sources:

- Friction losses - i.e., losses do to the interaction of duct velocity, duct diameter, air density, air viscosity, and duct surface roughness.
- Fitting losses - i.e., losses do to the directional changes and diameter changes.

Both of these types of losses result in decreased efficiency and flow through the duct. Consult the ACGIH, *Industrial Ventilation: A Manual of Recommended Practice* when designing duct for principles to lessen these two types of losses.

2.

Manifolded exhaust systems use a limited number of large fans to service a series of similar operation exhaust intake systems. These multiple-unit systems require less total ductwork and less internal space for their ductwork.



- When materials exhausted are compatible (including radiological and chemicals aspects), manifolded fume hood and ducting exhausts is allowed.

By combining the exhaust systems, sufficient mass can be achieved for an outlet velocity at the stack sufficient to break through the recirculation zone on the roof. A manifolded system also offers opportunities for energy recovery, flexibility, and redundancy. Manifolded exhaust systems have lower energy consumption than individual fume hood systems. A single exhaust fan, with a back-up unit, in a manifolded duct system typically has higher energy efficiency than numerous lower power fans working independently.

Balancing- When designing a system with multiple branches, provide a means of distributing flow between branches by:

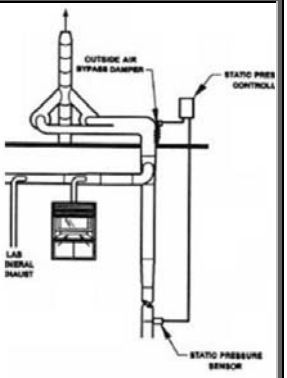
- A balanced design (validate using the "Static Pressure Balance Method" in the ACGIH, *Industrial Ventilation: A Manual of Recommended Practice*);
- Automatic balancing valves; or
- Use of blast gates (with highly toxic material, provide a mean to prevent tampering with the gate settings).

3.

Negative pressure in occupied areas: Exhaust system should not be under positive pressure inside the normally occupied areas of buildings. This is a safety measure to prevent leaks of the ducted contaminant from entering the breathing zone of building occupants.

4.

Bypass Inlet Damper: Using an inlet damper at the central exhaust fan provides a constant exhaust velocity while insuring a constant duct static pressure. This constant volume control approach does not save exhaust fan energy but does reduce the amount of exhausted conditioned air from the facility.



Alternatively, variable frequency drives can be used.

5. **Minimum Duct Velocity: The** velocity needed to be maintained inside a duct is determined by the type of material being transported inside the duct. Particulates need a minimum velocity sufficient to keep the particulate from settling and clogging the duct. Too high of velocity is wasteful for power and can lead to rapid erosion of the duct from abrasion.

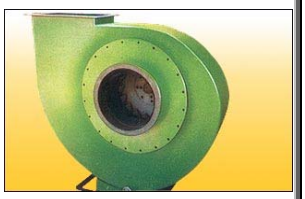
Examples of ideal design criteria for *Minimum Duct Velocities*

Contaminant Type	Example	Duct Velocity (fpm)
Gases, vapor, smoke	Gasoline	1000-2000
Fumes	Welding	2000-2500
Fine dust	Wood flour	2500-3000
Dusts and powders	Cotton dust	3000-4000
Industrial dust	Grinding dust	3500-4000
Heavy Dust	Sawdust, metal turnings, sand blasting	4000-5000
Moist or Dusts	Moist cuts	4500 +

6. Fans can be divided into two basic types based on blade orientation: Axial and Centrifugal (with variations of each). Each type has design and performance characteristics that make it better in some circumstances and worse in others. Consult the ACGIH, *Industrial Ventilation: A Manual of Recommended Practice* for details.

Axial- (propeller fan, blade fan) higher flow rates at low resistances

Centrifugal- lower flow rates at high resistances



7. **Optimum Design characteristics:**

- Use round duct for industrial ventilation, air pollution and dust collecting systems. It provides lower friction and higher structural integrity. Spiral round duct can be used for non-abrasive to moderate abrasive applications. Use rectangular duct only when space precludes round duct use.
- Use elbows and bends that are a minimum of two gauges heavier than straight runs and have a centerline radius 1.5 to 2 times the pipe diameter.
- Taper transitions in duct diameter at 30° to 45°.
- Use a straight duct section of at least 6 diameters when connecting to a fan.
- Avoid the use of flexible ducts, where practical.
- The material of duct construction and gages of are dependent on the contaminant. Heavier gage is needed for abrasive particulates. Systems made of stainless steel have the highest resistance to corrosion and longest service life. Consult the ACGIH, *Industrial Ventilation: A Manual of Recommended Practice* for guidance on material of construction.
- Sealing methods for junctions in ducting include welded joints, duct sealer, tape.

Criteria for design, use, testing and maintenance

1. Manifolded exhaust systems: At the acceptance test stage, verify proper balancing of the system using the *Static Pressure Balance Method* in the ACGIH, *Industrial Ventilation: A Manual of Recommended Practice*.

2. Exhaust Systems used at BNL as engineering controls necessary to prevent exposure to worker above an occupational exposure limit, need to be:

- Tested on start-up to ensure that the control reduces exposure to acceptable limits, and
- Tested on a frequency determined by the SME to validate continued proper operation.

3.	Leak test a system at the design operating static pressure prior to placing in service. Leakage should be no more that 1% of the design volume.
4.	Provide fire dampers and explosion vents in accordance with NFPA and other applicable codes. Provide appropriate explosion proof fans for systems handling explosive or flammable atmospheres.
5.	If no other hazards make it unadvisable, provide a flexible connection between duct and fan to allow for vibration isolation and expansion.
6.	Provide probe openings with threaded caps in the duct for routine system testing.
7.	Minimize fan noise and vibration. Obtain noise rating from the fan manufacturer. All fans produce a noise that includes most frequencies. Radial fans also produce a pure tone at a frequency equal to the rotational rate per second x the number of blades.
8.	Inspect fan on a periodic basis, to include: • Bearings lubrication; • Excessive vibration of bearings or housing; • Belt drives; • Correct coupling alignment; • Fan impeller alignment and rotation; • Impeller wear or material accumulation.

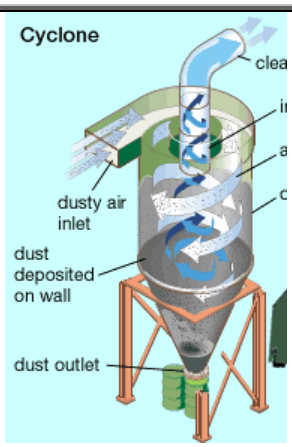
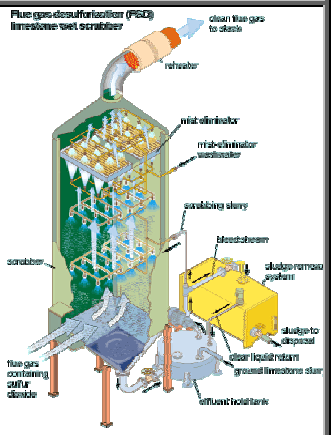
Air Cleaning Technologies (including HEPA Filtration)

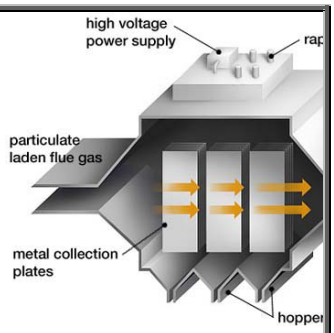
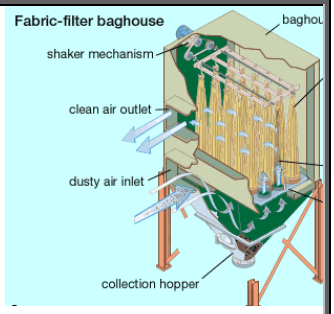
Principles of Air Cleaning Technologies

Removal of contaminants out of the work area and dilution into the environment is often an effective control method for reducing the concentration of toxic effluents for workers. However, for some materials, this direct release of contaminant to the environmental may not be in conformance with environmental protection laws. In these cases, a means for cleaning the exhaust air (scrubber, filters, etc.) need to be employed.

Airborne hazards can be removed from a polluted air stream by a variety of physical processes. Common types of equipment for collecting fine particulates include cyclones, scrubbers, electrostatic precipitators, bag houses, and filters.

- Particulate characteristics that influence the selection of collection devices include corrosivity, reactivity, shape, density, particle size and size distribution.
- Other design factors include air stream characteristics (e.g., pressure, temperature, and viscosity), flow rate, removal efficiency requirements, and allowable resistance to airflow.

1.	**Cyclone collectors** remove particulates by causing the dirty air stream to flow in a spiral path inside a cylindrical chamber. Dirty air enters the chamber forming a vortex as it swirls within the chamber. The larger particulates, because of their greater inertia, move outward and are forced against the chamber wall. Slowed by friction with the wall surface, they then slide down the wall into a conical dust hopper at the bottom of the cyclone. The cleaned air swirls upward in a narrower spiral through an inner cylinder and emerges from an outlet at the top. Accumulated particulate dust is periodically removed from the hopper for disposal. Cyclones are best at removing relatively coarse particulates. They can routinely achieve efficiencies of 90 percent for particles larger than about 20 micron (0.0008 inch).	
2.	**Wet scrubbers** trap suspended particles by direct contact with a spray of water or other liquid. A scrubber washes the particulates out of the dirty air stream as they collide with and are entrained by the countless tiny droplets in the spray. In a spray-tower scrubber, an upward-flowing air stream is washed by water sprayed downward from a series of nozzles. The water is recirculated after it is sufficiently cleaned to prevent clogging of the nozzles. Venturi scrubbers are the most efficient of the wet collectors, achieving efficiencies of more than 98 percent for particles larger than 0.5 micron (0.00002 inch) in diameter. Scrubber efficiency depends on the relative velocity between the droplets and the particulates.	

3.	**Electrostatic precipitation** is a commonly used method for removing fine particulates from airstreams. In an electrostatic precipitator, particles suspended in the air stream are given an electric charge as they enter the unit and are then removed by the influence of an electric field. The precipitation unit includes baffles for distributing airflow, discharge and collection electrodes, a dust clean-out system, and collection hoppers. A high DC voltage (as much as 100,000 volts) is applied to the discharge electrodes to charge the particles, which then are attracted to oppositely charged collection electrodes, on which they become trapped. Electrostatic units have a 98% efficiency rate of filtration for welding fume and smoke.	
4.	**Bag houses** remove suspended particulates in an assembly of fabric filter bags. A typical bag house has an array of long, narrow bags that are suspended upside down in a large enclosure. Dust-laden air is blown upward through the bottom of the enclosure by fans. Particulates are trapped inside the filter bags, while the clean air passes through the fabric and exits at the top of the bag house. A fabric-filter dust collector can remove very nearly 100 percent of particles as small as 1 micron (0.00004 inch) The bags are cleaned by mechanical shakers or by reversing the flow of air, and the loosened particulates are collected and removed for disposal.	
5.	**Air Filters & Dust Collectors:** • The term ***Air Filter*** is typically used for low efficiency collection devices designed for low atmospheric concentration of dust. These are typically used in HVAC (air conditioning and heating systems).	
	• ***Dust Collectors*** use paper or fabric filters to capture particulates. They typically handle much higher concentrations of particulates, such as those in industrial applications like local exhaust systems and process stacks.	
	• **HEPA Filtration:** HEPA dust collection filters trap 99.97% of airborne particulate down to 0.3 microns in size. The life of a HEPA filter can be increased 25 % with a throwaway pre-filter. Adding a 90% efficiency pre-filter can extend the HEPA filter life up to 900%.	

Criteria for design, use, testing and maintenance

1.	Chemical Adsorbers: Use **adsorbers** only in appropriate applications. Adsorber are to be used as an exhaust system air pollution control device only as required to remove a hazardous gases and vapors or radiological gases). The Chemical or Radiological SME establishes testing frequency to determine saturation of the media.
2.	Use **HEPA filtration** only in appropriate applications. HEPA filters are to be used as an exhaust system air pollution control device only as: • Required to remove a hazardous particulate (such as lead, asbestos, highly hazardous chemicals, biological or radiological particulates). • When installed and maintained as per the Exhaust Ventilation Subject Area requirements.

3.	**HEPA Filter Use & Decommissioning:** When installed HEPA filters are no longer needed, one of the following actions must be taken: • Remove the filters from the housing by following the procedure in the section Decommissioning, Modifying, or Changing the Operational Status of Fixed Exhaust Ventilation Systems in the Exhaust Ventilation Subject Area; or • Shut down and seal the exhaust system by following the procedure in the section Decommissioning, Modifying, or Changing the Operational Status of Fixed Exhaust Ventilation Systems in the Exhaust Ventilation Subject Area; • Maintain the filters and system as per the Exhaust Ventilation Subject Area requirements and this handbook when the filters are left in the exhaust system.
4.	**Air Pollution Control System <u>Initial Acceptance Testing</u>**: This section applies on new installation of fixed HEPA Filter systems. A. **Nuclear:** HEPA filtered and/or adsorber exhaust systems installed <u>in DOE Category 1, 2 and 3 nuclear facilities applications</u> are to meet the design specifications of ANSI/ASME N509-2002, *Nuclear Power Plant Air-Cleaning Units and Components.* Units need to be tested and certified by an independent source per ANSI/ASME N510, *Testing of Nuclear Air Treatment Systems* (Acceptance tests) prior to accepting the design & installation work. B. **Non-nuclear:** HEPA filtered and/or adsorber exhaust systems installed as a pollution control device for radiological hazards are to meet the appropriate portion(s) of the design specifications of ANSI/ASME N509-2002, *Nuclear Power Plant Air-Cleaning Units and Components* (or other approved criteria) as determined by the RCD Manager or designee. The system needs to be tested and certified per the appropriate tests from ANSI/ASME N510, *Testing of Nuclear Air Treatment Systems* or other approved specification (determined by the RCD manager or designee) prior to accepting the design and installation work. C. **Chemical:** HEPA filtered and/or adsorber exhaust systems installed as a pollution control device for <u>OSHA Regulated Chemicals</u> are to meet the appropriate portion(s) of the design specifications determined by the SHSD Manager or designee. The system needs to be tested and certified per tests (determined by the SHSD Manager or designee) prior to accepting the design & installation work. Units passing the test are to be labeled with the organization performing the test, date of test, and date of next test due.
5.	**Air Pollution Control System <u>Periodic Surveillance Testing</u>**: A. **Nuclear**: HEPA filtered and/or adsorber exhaust systems installed in <u>DOE Category 1, 2 and 3 nuclear facilities applications</u> are to be tested and certified per ANSI/ASME N510, *Testing of Nuclear Air Treatment Systems* Section 10 *In-place test* (Surveillance tests) at each filter change and on an annual basis or other frequency is established in a nuclear licensing permit. B. **Non-nuclear:** HEPA filtered and/or adsorber exhaust systems installed in fixed exhaust ventilation systems used as pollution control devices for radiological hazards are to be tested and certified as per ANSI/ASME N510, *Testing of Nuclear Air Treatment Systems,* Section 10 - In-place test (surveillance tests) at each filter change and on an annual basis or at other frequency established by the RCD Manager or designee. C. **Chemical:** HEPA filtered and/or adsorber exhaust systems installed as a pollution control device for <u>OSHA Regulated Chemicals</u> are to be tested to specifications and at a frequency determined by the SHSD Manager or designee. Units passing the test are to be labeled with the organization performing the test, date of test, and date of next test due.

	Note: Product integrity filters HEPA filtered exhaust systems installed only as product integrity control devices (for example some clean rooms and laminar flow hoods) should be tested as per the user's specification requirements to meet product quality needs.
6.	**HEPA Filter System differential pressure indicator:** A. **Nuclear:** HEPA filtered exhaust systems installed in DOE Category 1, 2, or 3 nuclear facilities applications needs to be provided with a pressure drop monitoring instrumentation needs to be provided across the HEPA filter. • This instrumentation needs to be readable at the operator station and the operator needs to keep a monthly log of pressure drop readings. • A filter change is required when pressure drop exceeds the applicable criteria of: a. manufacturer's recommendations; b. 2 inches water gauge (when the starting pressure is less than 1 inch water gauge); c. twice the original pressure (when the starting pressure is greater than 1 inch but less than 2 inches water gauge); d. other specifications set by a Professional Engineer or Technical Specification criteria. B. **Non-nuclear:** HEPA filtered exhaust systems installed in fixed exhaust ventilation systems as pollution control devices need to be provided with a pressure drop monitoring or indicating instrumentation across the HEPA filter. • The operator needs to keep a monthly log of pressure drop readings and initial pressure readings after filter replacement. • A filter change is required when pressure drop exceeds the applicable criteria of: a. manufacturer's recommendations; b. 2 inches water gauge (when the starting pressure is less than 1 inch water gauge); c. twice the original pressure (when the starting pressure is greater than 1 inch but less than 2 inches water gauge); d. other specifications set by a Professional Engineer or Technical Specification criteria. C. **Chemical:** HEPA filtered exhaust systems installed in fixed exhaust ventilation systems as pollution control devices need to be provided with a pressure drop monitoring or indicating instrumentation across the HEPA filter. • A filter change is required when pressure drop exceeds the applicable criteria of: a. manufacturer's recommendations; b. 2 inches water gauge (when the starting pressure is less than 1 inch water gauge); c. twice the original pressure (when the starting pressure is greater than 1 inch but less than 2 inches water gauge); d. other specifications set by a Professional Engineer or Technical Specification criteria.
7.	**HEPA Filter Degradation with Age:** A. **Nuclear:** HEPA filters for DOE Category 1, 2, or 3 nuclear facilities applications need to be removed when the age exceeds specifications set by a Professional Engineer or Technical Specification criteria. When specifications are not set, filters needs to be removed if the filter is not capable of passing surveillance testing criteria or exceeds 120 months after the date of installation. B. **Non-nuclear:** HEPA filters in fixed exhaust ventilation systems as pollution control devices need to be removed when the age exceeds specifications set by a Professional Engineer or

	Technical Specification criteria. When specifications are not otherwise set, filters needs to be removed if the filter is not capable of passing surveillance testing criteria or exceeds 120 months after the date of installation. C. **Chemical:** HEPA filtered exhaust systems installed in fixed exhaust ventilation systems as pollution control devices need to be provided with a pressure drop monitoring or indicating instrumentation across the HEPA filter. When specifications are not otherwise set, filters needs to be removed if the filter is not capable of passing surveillance testing criteria or exceeds 120 months after the date of installation.
8.	HEPA Filter Storage and Handling: Filters need to be stored as follows: A. Stored in the original container from manufacturer at less than 120°F. B. Stored in environmental conditions meeting conditions specified by the manufacturer. C. Inventoried with a "first in, first out" rotation. D. Not stored in excess of time limits specified by the manufacturer. E. Not installed if the filter age (i.e., shelf life) is more than 36 months (3 years) from the date of *receipt at BNL.* See the Materials Requiring Special Handling (Including Age Sensitive Material) Subject Area for requirements for labeling and for categorizing the filters.
9.	HEPA Filter Procurement: A. Nuclear: HEPA filters installed in DOE Category 1, 2, or 3 nuclear facilities applications are to be purchased from the DOE Filter Test Facility (FTF) Certified Independent Quality Assurance testing source, or a DOE approved equivalent source. • Procurement Specifications need to require the filter to be approved by the DOE FTF or other DOE established equivalent process. • Filter Acquisition: Filters need to be purchased by Purchase Order through the BNL Procurement and Property Management Division. B. Non-nuclear: All other HEPA filters for radiological and chemical hazards do not require DOE FTF Certified Independent Quality Assurance testing.
10.	HEPA Filtered Vacuum Cleaners: A. HEPA filtered vacuum cleaners used on DOE Category 1, 2, and 3 nuclear, radiological, or OSHA Regulated Chemical hazards are to be • Evaluated under Work Planning and Control. • Tested for *Installation mounting and filter integrity* at each filter change and on an annual basis (unless another frequency is established by the BNL Exhaust Ventilation SME). Units passing the test are to be labeled with the organization performing the test, date of test, and date of next test due. B. HEPA filtered vacuum cleaners used on radiological hazards must meet requirements of the Radiological Control Manual. HEPA filtered vacuum cleaners should be labeled with the hazard name and controlled to minimize waste disposal costs. Examples are labeling on the exterior of unit for the intended hazard (e.g., *Mercury only, Radiological only, Chemical only, Asbestos only, Non-hazardous only, Mixed Waste only*, etc.).

Discharge Design

Principles of Exhaust System Discharge Design

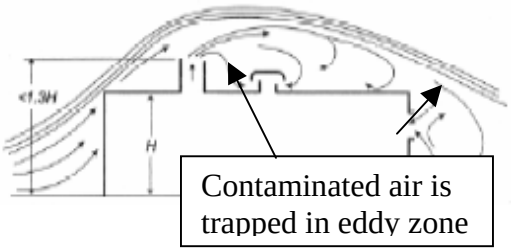
Worst-case conditions need to be considered when designing stacks for laboratory hoods, or general-purpose ventilation systems. Because of the complex airflow patterns around buildings, it is almost impossible to locate an exhaust discharge that is not influenced by the wind. The following designs principles help maximize the success of exhaust systems.

1. Two main types of exhaust discharge designs are used:

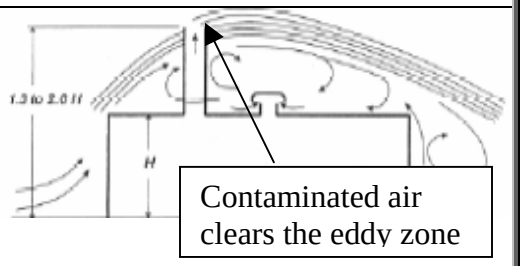
- **Exhaust stack-** The stack releases the contaminant at a point above the eddy zone of the structure. The high point of release helps prevent re-entrainment of the contaminants back into the building via air intakes and wall openings.

- **Ventilator dome-** The dome releases the contaminant at a point within the eddy zone of the building. The low point of release does not prevent re-entrainment of the contaminants back into the building via air intakes and wall openings. This type exhaust should only be used for non-toxic (odor) and humidity control from kitchens and baths and for heat control.

2. Airflow around buildings creates a positive pressure zone on the upstream side and negative pressure zones (eddy zones) on the roof and on sides of the building. When effluents are released a short distance above the roof, the gases may be trapped within the eddy zones. This may contaminate the intake air for the building.
Occurs when building height + stack is <1.3 x building height.



To ensure discharge away from a building, the effluent must be discharged above the building eddy zone, which is accomplished by increasing the height of the stack. High-velocity vertical discharge can be used to add to the effective stack height.
Ideal building height + stack height = 1.3 to 2 x building height.



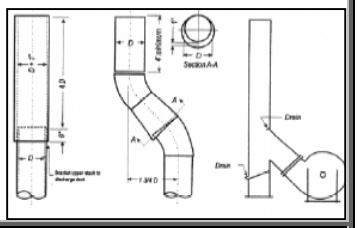
The height of the building's eddy zone may be 1.3 to 2.0 times the building height for one- and two-story buildings. Its height also depends on the surrounding terrain and the building width to height ratio. When the width of the building increases relative to the height, the eddy zone also increases. However, increasing the building height alone does not significantly change the eddy zone.

3. Wind movement around stacks creates turbulence that hinders the escape of toxic exhaust. This turbulence will bring the air down toward the building, thus reducing the effective height of the stack.

4. Ideally, locate the air intake upwind of the source. At BNL that typically means the west side of a building. However, because of the variable nature of wind patterns, there is often no true upwind

	position, and the ultimate reliance needs to be on meeting the proper stack height design principles. Locate the air intake lower on the building to help prevent entrainment.

Criteria for design, use, test, and maintenance

1.	Stack discharge velocity needs to be checked, before use of the system for toxic materials, to ensure proper operation.
2.	Separate exhaust stacks need to be used for general-purpose hoods involving the use of materials, which may be <u>incompatible</u> when exhausted through a common exhaust stack.
3.	Toxic discharge needs to be exhausted through ventilation systems by use of a high stack, with the following characteristics: • For buildings up to 14 feet in height, the stack needs to be **7 feet** (2 meters) in height. • For all other buildings or high structures the stack needs to be **10 feet** (3 meters) in height. • Vertical discharge from the stack located on the highest point of the building, when possible. The optimum shape is a straight cylinder.
4.	The discharge from the stack needs to have a velocity of at least **3000 feet per minute at the stack opening (when the stack height meets the height criteria in #3.** Rain has a terminal velocity of 2000 fpm (22 mph). To prevent rain from entering the stack, the discharge velocity needs to exceed 2600 fpm.
5.	Effective stack height can be increased by high discharge velocity fan strobic units, when needed, to extend discharge exhausts above the building's eddy zone. Discharge velocities up to 8000 fpm may be needed for a flush mounted stack.
6.	Construction of the stack assembly needs to be of appropriate non-corroding materials. Stacks need to be constructed to provide sufficient resistance to wind, i.e., guy wires or clustering.
7.	Provision for drainage of rainwater and condensation accumulated during non-operative periods needs to be provided. 
8.	Weather caps, which deflect the effluent downward, are not to be used for hazardous contaminant use.

Perchloric Acid Hoods and Exhaust Systems

Principles of Perchloric Acid Exhaust System Design

Perchloric acid is a very strong oxidizer. When perchloric acid is heated above ambient temperatures, it will vaporize and condense on interior surfaces. When the acid reacts with organic material, an **EXPLOSIVE** reaction product may be formed. This can result in deposits of highly explosive metal perchlorates in hoods, ducts, fan housing, and other system components. Hammering, banging, and parts disassembly can result in very hazardous explosions and subsequent injury of maintenance or construction personnel.

To prevent this hazard, when perchloric acid is used in quantities that can create the explosion hazard in the exhaust system, all work must be done in specifically designed **"perchloric acid/perchlorate" hoods** with a "wash down" system. By washing down the hood and its ducting following each use, materials deposited are removed and prevented from building up to hazard levels.

Hood and exhaust system design

- Locate all utility controls outside the hood.
- Use nonreactive, acid-resistant materials; the following are acceptable: Stainless Steel Type 316, polyvinyl chloride (unplasticized), inorganic coating (e.g., porcelain) duct.
- Use an acid-resistant metallic fan with inorganic coating (e.g., porcelain).
- Incorporate a wash-down system with water collector.
- Duct the system individually, not manifolded.
- Lubricate the fan with fluorocarbon-type grease.
- Locate the fan outside of the building.

Criteria for design, use, test, and maintenance

The following *Special Provisions* must be specifically addressed in Experimental Safety Reviews (ESR) and Work Permits:

1. Surface Wipe sampling
2. Labeling of hoods
3. Wash down systems
4. Decontamination Plan

1.	**Wash down systems:** Use of perchloric acid where it is heated above its boiling point or otherwise made airborne must be done in specifically designed hood with a "wash down system," unless there is permission within the Work Planning review process with concurrence of Working with Chemicals SME.

2.	**Surface Wipe sampling:** A. When the process knowledge of the entire history is not known, testing of surface contamination of the hood interior and duct work is required before demolition or modification of any local exhaust system. B. When perchloric acid is heated to its boiling point in an exhaust system, the surfaces of the interior of the hood need to be tested on an annual basis while perchloric acid is in use. C. When perchloric acid has been heated to its boiling point in an exhaust system, the surfaces of the interior of the hood need to be tested at the end of a project. Contact the IH Representative or Facility Support Representative for testing.
3.	**Labeling of hoods**: Hoods that are currently in use with perchloric acid must be marked on the hood, ducting and discharge with appropriate warning. Ventilation equipment that has been tested is to be labeled with the date of testing and the status as "*Perchlorate contaminated*" or "Perchlorate Free".
4.	**Decontamination Plan:** A written Decontamination Plan must be addressed in Work Planning and Control documentation for any work done when perchloric acid is heated to its boiling point in an exhaust system.