CHAPTER D

Engineering controls are the first line of defense in controlling laboratory hazards. Wherever possible, it is preferable to “engineer” out the hazard through initial design specifications, or by implementing engineering controls such as ventilation or process change (e.g., substitution). Wherever engineering controls are not feasible or fully sufficient, they should still be used to the extent possible, but supplemented with administrative controls, the use of personal protective equipment, or a combination, as appropriate.

Although the effectiveness of certain engineering controls still depends on proper use and equipment maintenance, as a whole, engineering controls are much less dependent on human actions than the use of personal protective equipment or an administrative control such as training. Therefore, the potential for human error and subsequent exposure to laboratory hazards is minimized.

This chapter addresses the use of several types of engineering controls, as well as important considerations such as maintenance requirements and user training for EPA laboratories as follows:

Chapter	Topic
D2	Laboratory Design
D3	Process Change
D4	Ventilation
D5	Hazard-Specific Controls

1.0 Introduction

All laboratories should be designed according to basic principles that will enhance worker safety and health and minimize environmental impact. Numerous factors influence the efficient design, construction, and modification of an EPA laboratory. These factors include, but are not limited to:

- Location
- Size
- Type
- Task requirements
- Hazard containment needs
- Decontamination needs
- New construction versus retrofit
- Cost

Effective design requires careful consideration of the functions and activities to be performed within the laboratory. For example, proper design must ensure chemical containment. Designers of chemical-use laboratories must also give special consideration to the fire safety implications of barrier and containment features.

Since decisions pertaining to building design, construction, and laboratory preparation have far-reaching effects, consultations with an architect, a structural engineer, an industrial hygienist, and a quality surveyor are imperative.

This chapter addresses general design requirements for several types of engineering controls. For specific guidance on laboratory design, consult the *EPA Facility Safety, Health, and Environmental Management Manual* as well as federal, state, local, and EPA standards for the following:

- Ventilation
- Chemical storage
- Control of biologicals
- Fire safety
- Noise control
- Radiation safety
- Illumination

EPA Program Requirements

EPA laboratories must meet the laboratory design requirements discussed in this chapter, and are encouraged to follow the recommendations and best practices presented. Laboratories should be:

- Sufficient in size to accommodate the building and outbuildings with adequate setbacks that meet local and federal Resource Conservation and Recovery Act (RCRA) requirements

- Located in light-industrial areas with provisions to contain accidental spills

- Located in areas that have fully staffed emergency response personnel, including hazardous-material response teams

Laboratory design should include:

- Appropriate general ventilation systems with air intakes and exhausts located to avoid the intake of contaminated air

- Adequate, well-ventilated stockrooms

- Sufficient fume hoods and sinks

- Required safety equipment (e.g., eyewash and shower units, etc.)

- Arrangements for waste disposal

- Provisions to meet other requirements and guidelines outlined in Chapters D3, D4, and D5 of this manual

Laboratories that handle or store hazardous chemicals, flammable gases, flammable liquids or explosives, and biological agents should not be incorporated into design plans for EPA office buildings or other buildings that may be leased by the Agency. Also, laboratory facilities should not be established or expanded in existing EPA buildings that are mainly occupied by office space.

For design assistance for new laboratories in EPA-owned and EPA-leased facilities, or the modification of existing laboratories, refer to SHEM Guide 23 and the *EPA Facility Safety, Health, and Environmental Management Manual,* which provide guidelines for laboratory design and construction, including storage areas and installation of engineering controls.

Program Administration
To effectively manage the design, construction, and modification of EPA laboratories, responsibilities should be assigned to:

- Ensure that the design of laboratory facilities satisfies the requirements of the EPA; the National Fire Protection Association (NFPA); General Services Administration (GSA); and Occupational Safety and Health Administration (OSHA). State and local building and fire prevention codes must be met as well. The most stringent criteria will prevail, if conflict exists.

- Conduct work-area surveillance that includes an assessment of engineering controls and design features.

- Prepare written standard operating procedures (SOPs) with reference to the SHEM Guide 23 section on the storage of flammables, compressed gases, and other chemicals.

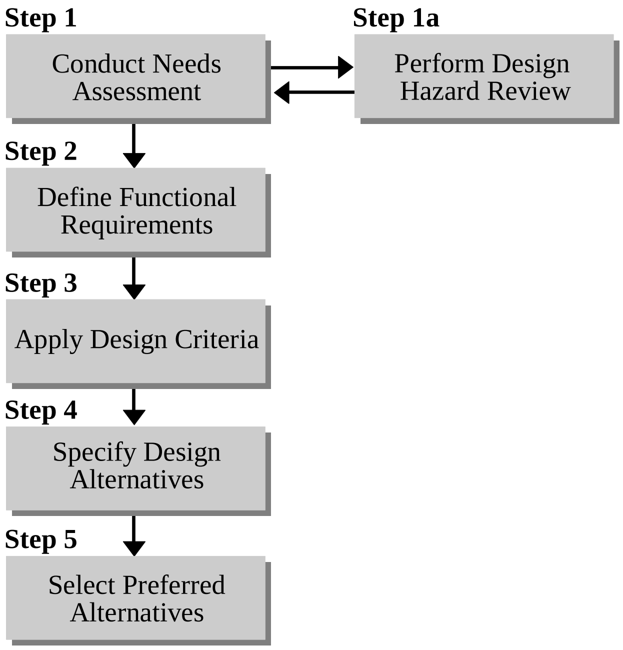
- Perform and document a safety, health, and environmental (SHE) review as part of any laboratory design, construction, and/or modification project.

2.0 Design Process

A methodology for designing a laboratory is presented in Figure D2-1. The designer can modify this scheme for different types of laboratories, based on the types of operations to be performed and the staff who will be using the space.

To design a laboratory, there is a sequential process that must be followed. The steps, summarized below, include conducting a needs assessment, carrying out a design hazard review, and developing design criteria.

Figure D2-1: Sequence of Laboratory Design Process



Laboratory Directors, Safety, Health, and Environmental Management Program (SHEMP) Managers, and laboratory staff should be involved in the design process, where feasible. Staff participation and input is especially important in the needs assessment and when specifying design alternatives. Laboratory personnel will likely have unique insight into laboratory operations as well as facility and equipment use.

2.1 Step 1: Conduct Needs Assessment

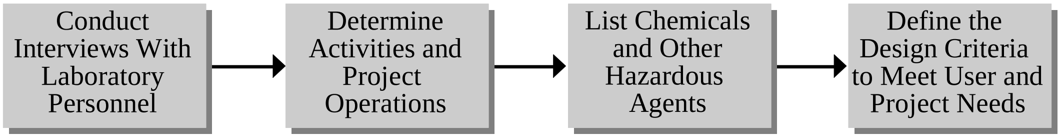
To design a laboratory, the first step is to conduct a needs assessment to gain an understanding of both the planned activities and the project requirements. This initial step should consider the employees who will be using the laboratory, equipment needs, and, most importantly, the future project needs. Figure D2-2 summarizes the components of a needs assessment.

The needs assessment should be a qualitative process review that can also identify any hazardous operations that should not be performed in a general-use laboratory. Once the needs assessment has been completed, the designer(s) can define the functional requirements of the laboratory and perform a design hazard review.

2.2 Step 1a: Perform Design Hazard Review

Once the functional needs of the laboratory have been identified and understood, the designer(s) can assess employee risk and employee protection alternatives. This type of review is known as a design hazard review (DHR). For general laboratories, a DHR should be performed for the laboratory as a whole. If specific projects introduce additional laboratory hazards that cannot be minimized with existing engineering controls and personal protective

Figure D2-2: Components of a Needs Assessment



equipment, a DHR should be performed as well. After the initial DHR, the Laboratory Director or SHEMP Manager should initiate a subsequent DHR if hazards associated with a new project(s) warrant it.

Information for DHR
- Description of the process
- List of raw materials and products
- Size and type of equipment
- Statement of potential hazards
- Recommendations for risk reduction

While performing a DHR for a laboratory process, the SHEMP Manager should identify any points of uncontrolled chemical, biological, and/or radiological exposure to laboratory staff. Also, the designer(s) should review each exposure point to ensure that equipment controls are adequate to eliminate the hazard. This review should cover the process from the receipt to the disposal of the hazardous agent.

2.3 Step 2: Define Functional Requirements

The needs assessment and information from the DHR must then be used to define the functional requirements of a laboratory. For example, based on the needs assessment, an organic prep laboratory used for extractions would require the following facilities and equipment:
- Solvent storage
- Exhaust ventilation
- Negative pressure
- Sinks
- Eyewash and shower facilities
- Fire protection

It is important to consider insight gained from the DHR the type of ventilation, fire protection, etc., will be based on hazards and risk.

2.4 Steps 3 to 5: Select Design

The laboratory designer(s) can construct a series of design criteria, based on the design review and needs assessment. An excellent source for design specifications is the *Guidelines for Laboratory Design*, by Louis DiBerardinis, et al. A comprehensive list of the elements of design for general laboratories can be obtained from this source. Some of these elements are shown in Attachment D2-1.

Attachment D2-1: Design Elements for General-Use Laboratories

Purpose:	To provide a list of elements to be used for design of general-use laboratories.
Instructions:	Refer to this list when considering what design elements should be included in a new or renovated general-use laboratory.

Attachment D2-1: Design Elements for General-Use Laboratories

1.0 Laboratory Layout
  1.1 Staff entry and egress
  1.2 Laboratory furniture locations
  1.3 Location of fume hoods
  1.4 Location of equipment
  1.5 Handicapped access

2.0 Laboratory Heating, Ventilation, and Air Conditioning (HVAC)
  2.1 Temperature control
  2.2 Laboratory pressure relationship
  2.3 Laboratory ventilation systems
    — Comfort ventilation supply air for laboratory modules
    — Recirculation of laboratory room air
  2.4 Exhaust ventilation for laboratory modules
    — Exhaust of general room ventilation air from laboratories
    — Air rates for laboratory hoods and other local exhaust air facilities
    — Chemical fume hoods
  2.5 Exhaust fans and blowers
    — Exhaust air cleaning for laboratory effluent air
    — Exhaust ducts and plenums

3.0 Loss Prevention and Occupational Safety and Health Protection
  3.1 Emergency considerations
    — Emergency fuel gas shutoff
    — Ground fault circuit interrupters
    — Master electrical disconnect switch
    — Emergency blowers
    — Emergency eyewash
    — Chemical spill control
    — Emergency cabinet
  3.2 Construction methods and materials
  3.3 Control systems
  3.4 Alarm systems for experimental equipment
  3.5 Hazardous chemical disposal
  3.6 Chemical storage and handling
  3.7 Compressed-gas cylinder racks

Source: DiBerardinis, L.J., et al., *Guidelines for Laboratory Design,* 2nd Edition, John Wiley and Sons, New York, 1993.

1.0 Introduction

There are many methods that can be used to control a hazard. Some methods of control have proven to be better than others. Process change is the first line of defense against exposure to a hazard. Ideally, a process change can be made that will improve quality, reduce production costs, reduce risk, and offset potential environmental impacts.

As with any type of change, process changes for controlling hazards and environmental impact must also go through the established channels and systems of the specific EPA laboratory. This will help ensure that all details of the process change have been considered, as well as any potential implications (e.g., impact on environmental permits). Refer to Chapter B4 of this manual for further information on change management. Process changes specifically related to pollution prevention are addressed in Chapter C9 of this manual.

This chapter introduces process change techniques that can be used to control hazards and environmental impacts.

EPA Program Requirements

Each laboratory must:

- Consider the use of engineering controls (e.g., process change) as the first step in hazard and environmental impact control.
- Conduct any process change in accordance with the established laboratory-specific procedures, as well as the guidance outlined in Chapter B4 of this manual and, if applicable, Chapter C9 of this manual.
- Evaluate the effectiveness of process changes.

Program Administration

To effectively manage laboratory process changes, responsibilities should be assigned to:

- Evaluate the technical applicability and feasibility of process change methods for hazard and environmental impact control.
- Coordinate potential process changes with all involved parties (e.g., safety, health, and environmental (SHE) specialists, maintenance personnel, researchers, etc.).
- Test and implement any approved process changes.
- Evaluate the effectiveness of any implemented process changes.
- Maintain necessary documentation associated with process changes.

2.0 Overview of Process Change Methods

There are several process changes that can be implemented to result in the favorable conditions mentioned. These changes are shown in Figure D3-1 and discussed in the following sections.

2.1 Substitution

Substitution is an effective method to control hazard exposure and potential environmental impacts, and is generally considered to be the first method of control. Substitution can take three forms:

- Substitution of materials
- Substitution of process
- Substitution of equipment

A combination of these forms of substitution can often be the best method of control.

2.1.1 Substitution of Materials

A substitute of nontoxic or less-toxic materials may be as effective as, or better than, the more hazardous material. Table D3-1 shows some common examples of material substitutions.

Table D3-1: Examples of Material Substitutions

Hazardous Material →	Substitute Material
Neat Reagents	Premixed Reagents
Neat Liquids	Pelletized Materials
Carbon Tetrachloride	Aliphatic Petroleum Hydrocarbons
Benzene	Toluene
Organic Solvents	Detergent-and-Water Cleaning Solutions

In the case of solvents, a substitution of water-based materials will generally provide an even greater level of protection for laboratory staff. When substituting chemicals, though, it is important to ensure that an unforeseen hazard or environmental impact does not occur along with the substitution.

2.1.2 Substitution of Process

The overall process or procedures within an operation may be changed to eliminate or reduce exposure to hazardous materials or situations and to minimize potential environmental impacts. Examples of process substitutions are shown in Table D3-2.

Figure D3-1: Methods for Process Change

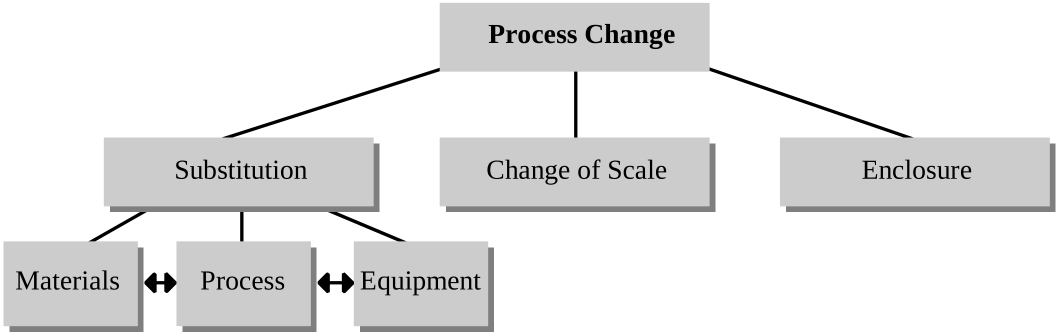


Table D3-2: Examples of Process Substitutions

Hazardous Process →	**Substitute Process**
Manual Material Handling	Automated Material Handling
Open System	Closed System and Equipment
Batch Processing	Continuous Processing
Carrying Containers of Toxic Materials	Using Pumping or Conveying Systems

Substitution of process also involves the redesign of procedures. This includes changing how the employee performs the task or interacts with equipment and the environment, or changing the frequency or duration of a task. Assessment tools such as a job hazard analysis can help identify the need for a change in how a process is designed. Similarly, an environmental audit can help uncover deficiencies in laboratory practices and procedures that may harm the environment.

Human factors engineering can be applied to the overall process and procedures to aid in the ergonomic design of laboratories, workstations, and tasks. Chapter C8 of this manual discusses ergonomic hazard prevention and control in more detail.

2.1.3 Substitution of Equipment

The use of specialized equipment, or adaptations to current equipment, can effectively reduce or eliminate exposure and mitigate environmental impact. Substitution of equipment includes the following examples:

- Use of guarding on existing mechanical equipment
- Use of automated equipment rather than manual
- Addition of pollution control devices to current systems
- Use of continuous area air monitoring for hazardous operations

2.2 Change of Scale—Micro and Mini Techniques

Changing the scale of the operation can be an effective engineering control method. Exposures and potential environmental impacts can often be minimized by handling and using smaller quantities of a material.

For instance, when working with volatile organic compounds or other toxic materials, the lower the quantity present and involved, the smaller the degree of volatilization and aerosolization. This reduces the employee inhalation hazard. Furthermore, using fewer compounds that have specific reportable quantities or thresholds may reduce the level of effort necessary for the laboratory to comply with environmental regulations that are triggered by the quantity of a chemical substance used, processed or produced (such as Comprehensive Environmental Response, Compensation and Liability Act [CERCLA] and Emergency Planning and Community Right-to-Know [EPCRA]).

2.3 Enclosure

Isolation of potentially hazardous operations is another hazard exposure control method. Typically, this isolation is provided in the form of a physical barrier.

Enclosure should be one of the first control measures considered after attempts to substitute are not successful. The use of enclosures is especially useful for jobs requiring relatively few workers and when control by other methods is difficult or impossible. The enclosure will isolate the hazardous job from the rest of the work operations, eliminating the exposures for the majority of the workers. For some operations, enclosing and isolating is essential. The process may generate contaminants in large quantities that fill a work area, exposing all workers to the hazard. Examples of enclosures for hazard exposure control include:

- Glove boxes
- Soundproof enclosures
- Heat barriers
- Separate, enclosed storage room for bulk material
- Laboratory fume hoods

1.0 Introduction

Proper ventilation is an integral part of Safety, Health, and Environmental Management Programs (SHEMP) at EPA laboratories. The general ventilation system should provide air for breathing and for input to local ventilation devices. Local exhaust ventilation is used to remove contaminants from the air at the point of generation. In laboratories, these air contaminants usually include particulates, vapors, gases, biohazardous agents, and radionuclides. Local exhaust ventilation prevents air contaminants from entering a worker's breathing zone and, for stationary work operations, is considered to be more reliable and protective than personal respiratory protective equipment.

Local exhaust ventilation systems can only be effective if designed and operated properly. Often, many monitoring and maintenance programs only concentrate on the visible components of the ventilation system (e.g., the hood), and ignore such ancillary equipment as ductwork, fans, fan stacks, etc.

Over the past 15 years, considerable research has focused on evaluating laboratory ventilation systems. This chapter summarizes this research and presents performance criteria that have resulted from new knowledge. The final portion of the chapter reviews evaluation and monitoring techniques, and presents information on inspection, routine maintenance, and user training. The topics covered in this chapter include:

- Ventilation systems overview
- Performance requirements
- Work practice guides
- Inspection and maintenance programs
- User training

EPA Program Requirements

Each laboratory must ensure that:

- Local exhaust ventilation systems are provided where needed for protection from toxic substances in the laboratory.

- All laboratory fume hoods:

  — Meet the construction and performance criteria contained in the SHEM Guide Manual

  — Have an American Society of Heating, Refrigerating, and Air Conditioning (ASHRAE) No. 110 standard performance rating as manufactured (AM)

  — Provide 80 to 120 linear feet per minute (fpm) of air flow

  — Are tagged "out of service" and reported to the building engineer for corrective action if they do not meet this criteria

- All local exhaust ventilation equipment is included in an inspection and maintenance program.

- Records of certification are maintained on-site.

- Employees are informed of the proper use and any required testing or inspection for the local exhaust ventilation equipment they use.

Program Administration

To effectively manage the laboratory ventilation program, responsibilities should be assigned to:

- Ensure that the design of the ventilation systems satisfies the provisions of current EPA, National Fire Protection Association (NFPA), American National Standards Institute (ANSI), and Occupational Health and Safety Administration (OSHA) ventilation requirements.

- Perform periodic checks of fume hoods and other ventilated equipment to ensure they are working properly.

- Coordinate an inspection and maintenance program for ventilation systems.

- Confirm that certification has been obtained and approved.

- Maintain records of certification.

- Provide employees with information on the proper use of, and any testing or inspection requirements for, local exhaust ventilation equipment.

2.0 Overview of Ventilation Systems

General ventilation provides room make-up air. Local exhaust ventilation is the primary method of contaminant control in the laboratory. Examples of exhaust ventilation control include laboratory fume hoods, biological safety cabinets, clean benches, and other local exhaust systems.

The following sections provide guidance on:

- General laboratory ventilation
- Fume hoods
- Biological safety cabinets
- Other exhausted enclosures

Although general laboratory ventilation is briefly discussed, this chapter is intended to focus primarily on local exhaust ventilation systems. Each of the examples of local exhaust ventilation systems are described in the following sections and summarized in Table D4-1.

2.1 General Laboratory Ventilation

General room ventilation is the least effective way to protect personnel from exposure to airborne contaminants such as gases, vapors, or particulates. This system should not be relied upon for protection against toxic substances released into the laboratory. Laboratory air should be continually replaced in order to prevent the increase of airborne concentrations of toxic substances during the workday. The airflow into the laboratory should be directed from non-laboratory areas to the exterior of the building.

2.2 Laboratory Fume Hoods

A fume hood is the primary hazard control device for protecting laboratory personnel. The common laboratory fume hood is simply an exhausted booth or enclosure that draws chemicals away from a worker's breathing zone. It is typically equipped

Table D4-1: Overview of Local Exhaust Systems

Local Exhaust System	Work Access Opening	Minimum Face Velocity (fpm)	Applicability	
			Carcinogens	Biohazards
Fume Hood	Sliding Sash	100	Yes	N/A
BSC Class I	Open Front	75	No	BSL3
BSC Class II		100		
Type A	Open Front		No	BSL3
Type B1	Sliding Sash		No	BSL3
Type B2	Sliding Sash		Yes	BSL3
Type B3	Sliding Sash		No	BSL3
BSC Class III	Front Panel With Gloves	N/A	Yes	BSL4

Notes: BSC - biological safety cabinet
BSL - biological safety level
fpm - feet per minute

with a rear baffle system to distribute the airflow evenly across the hood face, and a horizontal or vertical sash so that the hood opening can be minimized during use, and closed when not in use. Make-up air can be introduced directly to the laboratory fume hood (termed an "auxiliary air hood"); however, most often, make-up air is supplied by the room heating, ventilation and air conditioning (HVAC) system.

For ordinary laboratory operations, a well-designed and properly-installed fume hood should provide adequate protection for laboratory workers against airborne hazards. However, a laboratory fume hood cannot protect a worker against all materials and processes that may be contained in the hood. For instance, protection may be inadequate for materials with extremely low occupational exposure limits (i.e., those in the parts-per-billion range). In these circumstances, glove boxes or other totally-enclosing control systems should be used.

2.3 Biological Safety Cabinets

Three classes of biological safety cabinets (BSCs) are used in laboratories. In general, Class I, II, and III BSCs are used for work involving pathogens of low, moderate, and high virulence, respectively. Class II BSCs also protect materials handled inside the cabinet from external contamination. All BSCs are equipped with high-efficiency particulate air (HEPA) filters. Although HEPA filters protect operators from exposure to particulates, including bacteria, viruses, etc., they do not absorb chemical vapors and gases. For this reason, BSCs with recirculating air flow cannot be used for protection against toxic and/or irritating gases and vapors. Several types of BSCs recirculate air within the work space, and are inappropriate for use with toxic gases and vapors, since contaminants may accumulate. The various classes and types of BSCs are summarized below.

Class I BSCs

Class I BSCs are considered laboratory fume hoods, but the exhaust air is filtered through a HEPA filter, and no filtered air recirculates into the work space. Class I BSCs are designed to deliver a minimum face velocity of 100 fpm at the work access opening.

Class II BSCs

Class II BSCs provide a vertical laminar airflow into the work space, and also maintain an inward flow of air at the work opening. Like Class I, Class II BSCs have face velocities of at least 100 fpm. There are four types of Class II BSCs. The amount of air recirculation and the manner in which exhaust air is removed from the work space differs between the various types. Each of these is described in Table D4-2.

A typical airflow pattern for a Class II, Type A BSC is shown in Figure D4-1. Standard Class II, Type B1 and Type B2 BSCs are illustrated in Figures D4-2 and D4-3, respectively.

Class III BSCs

Class III BSCs, also known as "glove boxes," are gas-tight enclosures used for operations with the highest level of risk. As illustrated by Figure D4-4, access to the enclosed chamber is only possible through rubber gloves and sleeves that are integrated into the side of the cabinet. Air

Table D4-2: Types of Class II BSCs

Types of Class II BSCs
Type A
• Recirculate 70 percent of the HEPA-filtered exhaust air back within the cabinet; the remaining 30 percent is exhausted. • Filtered exhaust air may recirculate into the workroom air. • Face velocity is at least 100 fpm. • Meant to control airborne particulates only—inappropriate for use with toxic or irritating gases or vapors.
Type B1
• Only 30 percent of the exhaust air is recirculated into the cabinet. • Face velocity is at least 100 fpm. • Meant to control airborne particulates only—inappropriate for use with toxic or irritating gases or vapors.
Type B2
• 100 percent exhaust from enclosure; none of the air exhausted from the cabinet is recirculated. • All of the HEPA-filtered air is discharged either into an appropriate exhaust or back into the workroom air. • A second blower (fan) provides the vertical laminar flow. • Face velocity is at least 100 fpm. • Appropriate for use with toxic gases and vapors (as well as particulates) when connected to an exhaust duct with a safe release point outside the facility.
Type B3
• Recirculate 70 percent of the HEPA-filtered exhaust air back within the cabinet; the remaining 30 percent is exhausted. • Exhausts 30 percent of the air outside the building. • Face velocity is at least 100 fpm. • Meant to control airborne particulates only—inappropriate for use with toxic or irritating gases or vapors.

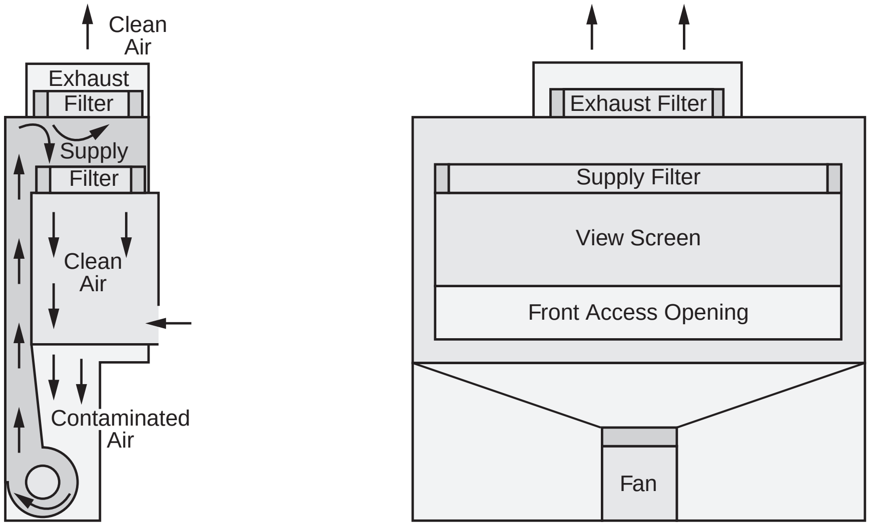
is swept across the work space through HEPA filters on both the supply and exhaust ducts.

2.4 Other Exhausted Enclosures

Other special systems for laboratory operations are available. They include:

- Vented benchtop workstations
- “Elephant trunks” (flexible ducts with cone or flanged inlet hoods)
- Laboratory bench slot hoods
- Extraction hoods
- Vented balance enclosures
- Glove boxes

Figure D4-1: Class II, Type A BSC



Vented benchtop workstations can be used for pipetting and for housing small centrifuges. These units should be equipped with a rear plenum to eliminate turbulence that normally occurs in standard hoods, and should provide laminar flow in the chamber that directs air away from the user. Vented benchtop workstations must not be used for chemical transfers.

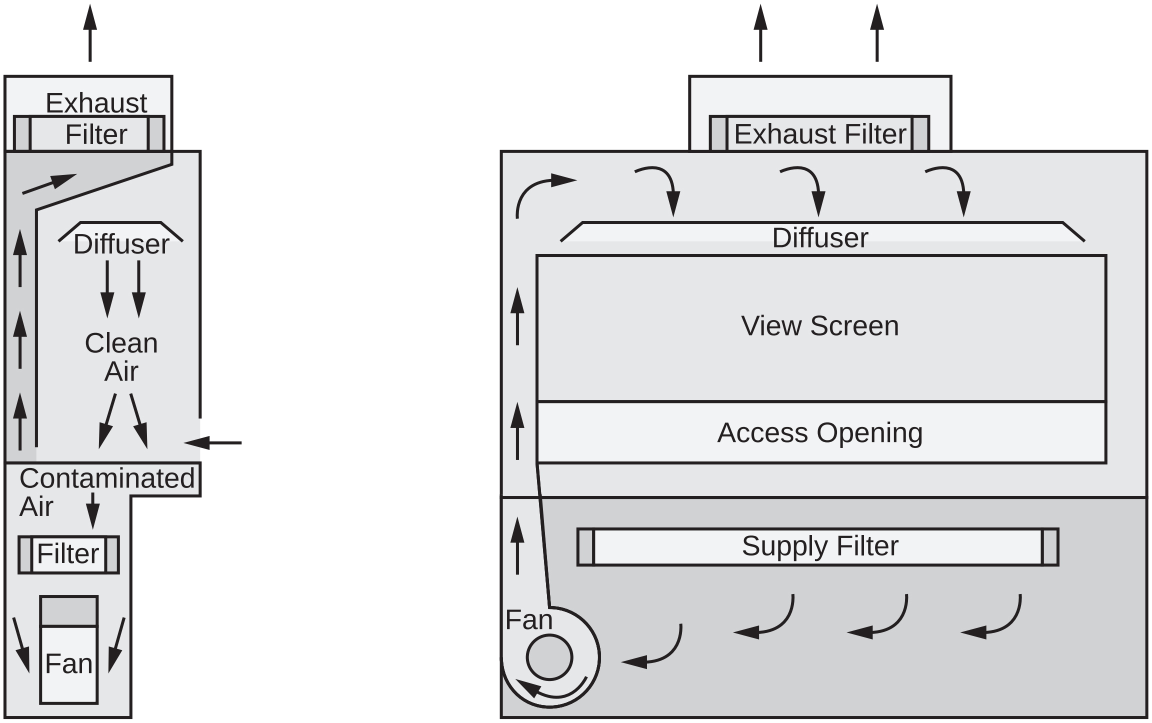
“Elephant trunks” with attached cone or flanged inlet hoods are typically used with gas chromatographic or other type of spectrophotometric analysis equipment.
Also, a vented balance enclosure can be used for protecting laboratory employees from inhalation hazards when weighing toxic or otherwise hazardous materials. The air capture velocity does not interfere with the weighing accuracy. In addition, the balance enclosure has been designed to provide maximum visibility, manipulation capacity, and worker comfort.

Note: Recirculating hoods equipped with charcoal or other filters are not recommended for protection against toxic chemicals. Refer to ANSI Z9.5 for more information.

3.0 Ventilation System Design

The design of an effective and efficient ventilation system is a technically complex and rigorous process. All designs should be developed or approved by a certified industrial hygienist or by a ventilation engineer experienced with both ventilation design and laboratory operations. Design efforts should be coordinated with all personnel involved, including the user, maintenance, SHEMP Manager and fire personnel. In addition to sound knowledge of ventilation principles, the design process requires an in-depth familiarity with both the range of tasks for which protection is required, and the variety of agents

Figure D4-2: Class II, Type B1 BSC



used. ANSI Z9.5 and ASHRAE 110 contain ventilation design criteria. EPA SHEM Guides must be consulted as well. In addition, OSHA and NFPA ventilation requirements must be met.

4.0 Performance Requirements

New exhaust installations should be inspected and tested prior to use. It is important to verify that the hood performance is adequate for intended use before working in the fume hood.

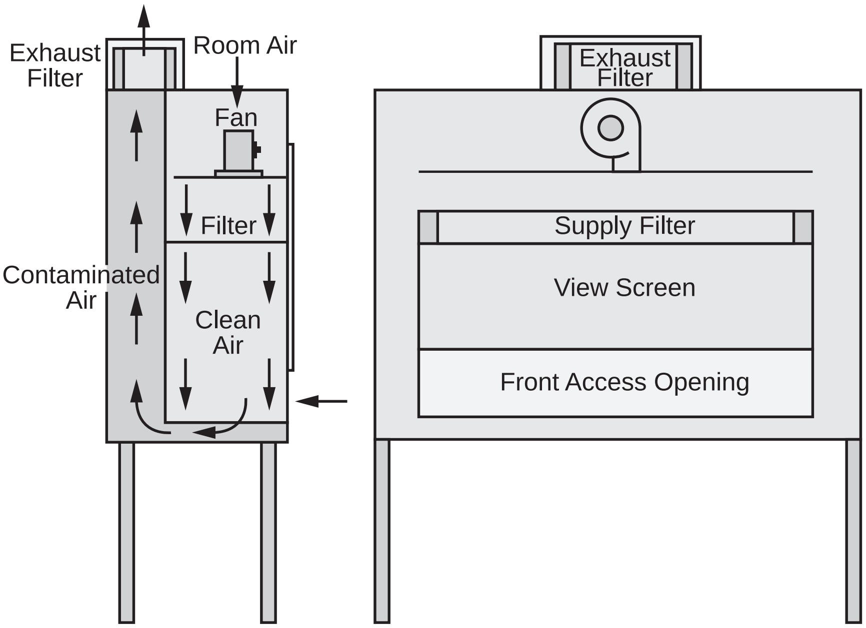
All laboratory fume hoods must meet the EPA construction and performance criteria, and must also have an ASHRAE 110 standard performance rating of 4.0 AM 0.05. The fume hoods must provide 80 to 120 fpm of air flow and be certified that they meet this velocity criteria before initial use. A copy of the initial certification must be forwarded to Safety, Health, and Environmental Management Division (SHEMD).

5.0 Work Practice Guides

The following work practice guides are primarily intended for the use of laboratory fume hoods, but can also be applied to the use of BSCs and other exhausted enclosures.

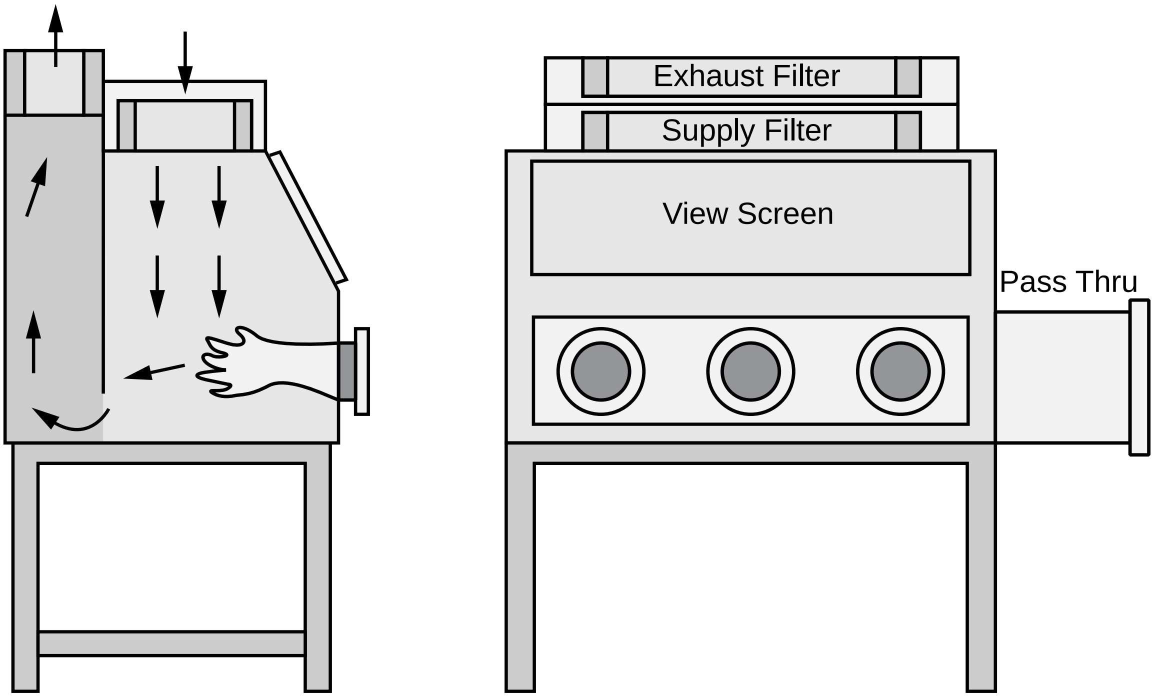
- Conduct all operations that release significant quantities of airborne materials inside a laboratory fume hood.

Figure D4-3: Class II, Type B2 BSC



- Keep all containers and apparatus at least six inches back from the front of the indicator marks on the hood base or side walls.
- Do not extend the head inside the hood when operations are underway.
- Keep all hazardous waste containers tightly closed at all times, except when additions are made to the container.
- Do not store unused chemicals or apparatus inside the laboratory fume hood. Instead, store chemicals in approved storage cabinets.
- Keep the hood sash closed as much as possible.
- Do not obstruct the slots or baffles in the rear of the hood.
- Minimize traffic past the hood.
- Keep laboratory doors and windows closed.
- Except for maintenance or repair, do not remove the hood sash, horizontal sliding safety panels, airfoil sill, or rear baffles.
- Use a safety shield or barricade if there is possibility of an explosion.
- For hoods that can be turned on and off in the laboratory, ensure that the hood is “on” whenever in use.
- Ensure that the laboratory fume hood system is adequately functioning and maintained. Do not work in a malfunctioning hood.

Figure D4-4: Class III BSC



6.0 Inspection and Maintenance Program

Where local exhaust ventilation is the primary control, regular inspection, testing, and maintenance of the ventilation systems are critical to ensure the protection of personnel from exposures to airborne hazards in the laboratory. Every monitoring program should include:

- Daily visual inspections
- Quarterly testing
- At least annual maintenance

Where applicable, the monitoring program for each piece of exhaust equipment should reflect the manufacturer's or designer's recommended operating practices. A document to use for assistance in hood inspection and testing is the "Procedure for Certifying Laboratory Fume Hoods to Meet EPA Standards." This document provides step-by-step procedures and worksheets for initial and periodic performance evaluations of laboratory fume hoods.

The following sections provide general guidance on inspection, testing, and maintenance procedures.

6.1 Inspection

Effective ventilation systems should demonstrate the following characteristics:

- Non-disruptive air patterns, including those inside the enclosure and those in the environment around the enclosure
- Adequate and appropriate face velocities and air flow volume

- Absence of leaks
- Properly functioning and well-maintained components

The inspection program should be designed to identify when these characteristics are not being met, as well as any warning signs of a potential problem.

The performance criteria below represent both quantitative and qualitative methods of assessing ventilation system performance and condition. Attachment D4-1 presents instructions for monitoring laboratory fume hoods and a sample hood monitoring form.

Before use of an exhaust system, operators should perform a visual inspection that includes checks of airflow, monitors and gauges, and housekeeping. Each are discussed in the following sections.

6.1.1 Airflow Check

When the exhaust system is operating, a flow indicator check, such as a ribbon or tissue paper check, should be performed to ensure that the exhaust is functional. This qualitative flow check is conducted by taping a small piece of tissue paper or plastic ribbon at the hood opening, and observing whether it reflects a directional air flow. For a glove box, the indicator should be placed inside at the exhaust slots. These indicators should not be allowed to escape into the exhaust system, as they can block the filter and reduce airflow.

6.1.2 Monitors and Gauges

All pressure gauges and other hood monitors should be checked for proper operation within a predetermined and indicated range. For pressure gauges, this range should be initially determined, for both the enclosure static pressure and the HEPA filter pressure drop, by a qualified health and safety professional or ventilation engineer. The precise range may vary between systems, and should be defined for each individual system.

6.1.3 Housekeeping

Any material blocking the hood opening or exhaust parts should be removed. Similarly, spilled material should be cleaned up, and soiled or damaged base-liner material replaced.

6.2 Testing

Periodic testing (e.g., quarterly) should be performed on local exhaust systems. For example:

- Smoke tube tests
- Face velocity measurements
- Additional tests

These tests are used, in conjunction with the daily inspections, to verify that local exhaust ventilation systems are working properly. Each are discussed in the following sections.

6.2.1 Smoke Tube Tests

Smoke tube tests should be performed quarterly to evaluate airflow patterns. Tests should be performed as follows:

Laboratory Fume Hoods or Class I BSCs (with or without auxiliary air supply)

The smoke should move from the plane of the sash directly to the rear exhaust slot, with the sash in its normal operating position. The smoke tube should be placed at and above the interior working space to locate any dead or turbulent spots. (*Note: turn off auxiliary air supply for test).*

Class II BSCs

The smoke should move from the plane of the sash into the forward intake grill. The smoke at the working area should move toward either the forward or rear exhaust slots with minimum turbulence.

Glove Boxes or Class III BSCs

Since these installations are gas-tight and maintained under negative pressure, a smoke tube test is performed to identify leaks around the joints and seals. The test is conducted by placing the smoke tube at the outside glove gaskets and inside the rubber gloves, and checking for evidence of smoke inside the box.

Other Local Exhaust Equipment

The smoke tube should be placed around the outer boundaries of the area to be exhausted or the zone of contaminant generation (e.g., the edge of a waste container that is exhausted along the back side, or the top of an atomic absorption spectrophotometer that is exhausted by a canopy hood). In all cases, the smoke should move directly into the exhaust inlet.

6.2.2 Face Velocity Measurements

Face velocities for laboratory fume hoods should be measured on a quarterly schedule. Face velocities for BSCs should be calculated and laminar downflow in the work space should be measured. These tests should be performed by qualified personnel using a properly calibrated, thermal or mechanical velometer.

EPA SHEMD requires that the face velocities of laboratory fume hoods be recertified at least annually, or after any significant maintenance, with recertification records maintained on-site.

The following procedures should be used for conducting face velocity measurements of laboratory fume hoods, BSCs, and glove boxes.

Laboratory Fume Hoods

The average of the velocities in each of nine points on a grid for a standard four to six-foot hood at the hood face will represent the overall face velocity. Measurements should be taken at full open or at a designated sash height (e.g., 18 inches, 20 inches). If the airflow is too low (i.e., less than 80 fpm), adjustments will be necessary to increase face velocity.

When these measurements are made, the auxiliary air supply (if present) should be turned off. If the hood is connected to other hoods, the face velocity should be measured under the maximum worst-case conditions (e.g., all the connecting hoods with sashes fully open and exhaust on). The average face velocity should be 80 to 120 fpm, with no individual point less than 80 fpm or greater than 100 fpm with a face velocity greater than 120 fpm must be checked with a smoke tube or candle to ensure that no backflow or eddies occur.

BSCs (laminar flow)

In Class II, Type A and B cabinets, the supply blower should be switched off for the face velocity measurement. The face velocity should be 100 fpm ± 10 percent. The vertical downflow of the supply blower should also be measured. The downflow at the work space should be approximately 50 to 80 fpm, depending on the manufacturer's recommendations.

Several types of Class II, Type B hoods are not easily switched off to determine face velocity measurements. For these cabinets, a combination of supply/working surface measurements and inlet smoke tubes tests should be performed by experienced personnel. If the inlet supply air is too great (e.g., greater than 80 fpm) and the smoke tubes indicate lazy inflow air patterns at the face, the supply/exhaust airflow may be out of balance, the HEPA filters may be overloaded, or the exhaust fan may be malfunctioning. In these cases, further testing or maintenance may be required.

Glove Boxes

If the glove box has a filtered air inlet without a supply blower, a velometer reading can be taken to determine the exhaust volume. The exhaust volume, in cubic feet per minute (cfm), is calculated by multiplying the average inlet velocity, in fpm, by the inlet area, in square feet. This exhaust volume for most manufacturers' specifications is in the range of 30 to 50 cfm. When a glove box has a supply air blower (the glove box airflow can be determined by measuring the air velocity at the fan inlet), periodic smoke tube leak tests (outlined above) should be conducted, and annual exhaust flowrate measurements should be taken.

The results of quarterly inspection and testing for all local exhaust ventilation systems should be recorded. These records should be kept in an accessible location so that users or maintenance personnel can refer to them when suspected malfunctions occur. In addition, laboratory fume hoods and other local exhaust hoods should be labeled with the design hood flowrate (e.g., cfm or m^3/s) and the hood flow resistance (e.g., static pressure or SP_h, inches or mm water gauge).

6.2.3 Additional Tests

Additional tests of exhaust slots and exhaust enclosures are recommended for verifying the effectiveness of local exhaust ventilation systems.

Exhaust Slots

Adjustable rear exhaust slots in laboratory fume hoods should be checked periodically for proper adjustment. Also, the supply and exhaust air flows in a BSC should be checked to determine if they are properly balanced. When the exhaust inflow and downflow are unbalanced, contaminated air may be forced outside the cabinet into the breathing zone of the worker.

Exhaust Enclosures

All exhaust enclosures should be smoke-tested to qualitatively demonstrate the effective capture of contaminants generated during normal operating procedures. The smoke test is conducted by placing a smoke tube inside the enclosure, and observing whether all the generated smoke is captured. If smoke leaks out of the enclosure, contaminated air may also leak out of the enclosure during normal conditions.

6.3 Maintenance

In addition to periodic inspection and testing, comprehensive annual maintenance of the entire ventilation system should be performed by qualified personnel. This section provides general maintenance guidelines, which should be used in conjunction with any specific recommendations provided by the manufacturer.

6.3.1 Exhaust Fan

Exhaust fan blades should be inspected for deterioration from corrosion, etc. The fan manufacturer should recommend the frequency and content of necessary maintenance, including lubrication and belt replacement.

6.3.2 Ductwork

The ductwork between the hood or exhaust inlet should be checked for leaks, corrosion, deterioration, and buildup of liquid or solid condensate. Although dampers are not recommended for laboratory exhaust systems, any dampers that are used for balancing the system should be lubricated and checked for proper operation and corrosion/erosion damage. Unused ductwork or old hood installations should be removed.

6.3.3 Air Cleaning Equipment

Charcoal or HEPA filters in the exhaust system should be monitored for contaminant buildup or breakthrough. Mechanical or absorbent filters not equipped with monitors (e.g., differential pressure gauges, audible alarms, etc.), should be leak-checked at least annually. Absorbent or adsorbent filters for gas and vapors can be leak-checked by challenge tests (i.e., release of a trace gaseous agent and use of a suitable detector). HEPA filters can be checked using the dioctylphthalate (DOP) method (see the National Sanitation Foundation [NSF] Standard for Class I Biohazard Cabinets [NSF Standard 49]). This type of test is often performed by an outside contractor.

6.3.4 Velocity Measurement

As mentioned earlier, total-exhaust Class II, Type B2 BSCs and glove boxes require exhaust air flow rate measurements to verify the proper airflow in the enclosures. In the total exhaust cabinet, the supply volume can be subtracted from the exhaust volume to yield the amount drawn in at the opening, and this value can be divided by the area of the average face opening to calculate the face velocity. For the glove box, the exhaust air flowrate range should be 30 to 50 cfm.

When these maintenance procedures are performed, suitable precautions should be taken to protect maintenance personnel from toxic contaminants inside the enclosure, ductwork, or filters. Any excess contaminated material or filters removed from the ventilation system should be disposed of according to the facility's approved hazardous waste disposal practices.

6.3.5 Special Tests for BSCs

There are special tests that are used to maintain and evaluate BSCs, which include, among others:

- Calculated inflow
- In-place leak testing of HEPA filters
- Ground continuity (containment and instruction)
- Noise level and vibration

Some of these tests may be performed by the manufacturer. However, the purchasing laboratory should arrange for testing and certification of each BSC at the time of installation, whenever the BSC is moved, and at least annually to ensure proper function. This is necessary since shipping, filter load, and installation of the BSC may alter performance. Testing should conform to the NSF requirements outlined in NSF Standard 49.

7.0 User Training

Before employees use any laboratory fume hood or other exhaust system, they should be trained in proper work practices and be familiar with hood operation and the required monitoring programs. Users should be trained on the work practices outlined in Section 3.4 of this chapter, as well as any guidance provided by the manufacturer.

The practice of daily visual inspections and smoke tube tests should also be included in the user training program.

Training on local exhaust ventilation systems is one of the recommended topics for the annual laboratory safety refresher training.

Attachment D4-1: Record for Laboratory Fume Hood Monitoring

Purpose: To serve as a recordkeeping form for laboratory fume hood monitoring.

Instructions: To use the form, follow these instructions:

1. Indicate the hood identification number (if applicable), location (e.g., room number, building), date of monitoring, and expected re-test date in the spaces provided.

2. Indicate the type of hood and the hood features, as shown. Include notes on any other features (e.g., filters), design characteristics, and special use conditions (e.g., use of radionuclides, perchloric acid, heating equipment).

3. Record readings from fixed, automatic measuring devices (e.g., magnahelic gauge, face velocity monitor). Describe other alarms, monitors, and gauges.

4. Note any interference with air inflow to the hood. Interference may be caused by windows, doors, busy walkways, supply air diffusers, etc., in the vicinity of the hood.

5. Adjust the hood sash height, if appropriate. Release smoke from a smoke tube at the face of the hood, along the front and at the bottom corners. The smoke should move smoothly and directly into the exhaust slot. Release smoke at or above the interior working space to locate “dead” or turbulent areas. Record the results of the smoke test in the space provided.

6. Using a calibrated velometer, measure the average face velocity of at least nine points for any hood that is four to eight feet long. (If applicable, turn off auxiliary air before measuring face velocity.) For hoods that are 8 to 12 feet long, double the number of measurements. Ideally, face velocity should be measured with sashes at full open. If measurements are not taken at full open, indicate the sash height.

   Add the values of each measurement and divide by the number of points measured to obtain the average face velocity. Multiply the hood length by its width to obtain the hood area, and multiply this value by the average face velocity to obtain the hood flowrate. Record these calculations in the spaces provided. Also indicate the type of instrument used to take measurements, and include its most recent calibration date.

   Face velocities for laboratory fume hoods should average approximately 100 ± 20 fpm. No individual point should be outside the acceptable range unless the smoke test demonstrates that the hood provides adequate capture without significant turbulence.

7. Based on the data generated, evaluate whether the hood needs adjustments or design modifications. Add other comments as necessary, and enter your name on the line provided.

Monitoring Record for Laboratory Fume Hoods

Hood Identification			**Date**		
Location			**Re-test Date**		
Types of Features					
Hood Manufacturer					
Bypass			**Auxiliary Air**		
Yes	No		Yes	No	
Flow Controlled (variable air volume)			**Connection to Other Hoods**		
Yes	No		Yes	No	
Adjustable Sashes					
Yes	No		Vertical	Horizontal	
Damper(s)		**Fan Switch**		**Bottom Air Foil**	
Yes	No	Yes	No	Yes	No
Other Features, Design Characteristics					
Special Use Conditions (e.g., radionuclides, perchloric acid)					
Automatic Measuring Devices					
Hood Static Pressure Monitor (in or mm w.g.)			**Hood Face Velocity Monitor (fpm or m/s)**		
Yes	No		Yes	No	
Other Alarms, Gauges, etc.					
Yes			No		
Capture Test					
Interference from doors, windows, walkways, supply air diffusers			Yes	No	
Smoke Test Results					
Face Velocity Measurements					
Test device		**Calibration date**		**Hood flow rate (cfm or m^3/s)**	
Sash height (non-VAV hoods) (in or mm)		**Hood flow rate cfm or m^3/s)**		**Hood area (sash open) (f^2 or m^2)**	
Hood Adjustment Indicated					
Yes			No		
Comments					
Tested By (signature):					

1.0 Introduction

Engineering controls must be applied based on the specific hazards present in the laboratory and the degree of potential risk associated with the hazards. This chapter addresses the following specific hazards that may be present in EPA laboratories:

- Chemical
- Biological
- Radiation
- Fire
- Noise
- Poor lighting

EPA Program Requirements

To effectively implement hazard-specific engineering controls, EPA laboratories must:

- Evaluate laboratory hazards
- Design, purchase, and implement appropriate controls
- Train employees in proper use of engineering controls
- Implement an inspection and maintenance program for control equipment

Program Administration

For effective control of laboratory hazards, responsibilities should be assigned for:

- Assessing laboratory hazards
- Selecting engineering controls
- Training employees in proper use of controls
- Inspecting engineering controls
- Evaluating the effectiveness of applied controls

2.0 Chemical Hazards

Engineering controls must be the primary means of controlling hazards presented by laboratory chemicals. This section provides information and guidance for work surfaces, chemical storage, and containment as shown in Figure D5-1. Certain chemicals used in EPA laboratories specifically require the use of engineering controls based on the individual the U.S. Occupational Safety and Health Administration (OSHA) standards.

2.1 Work Surfaces

Contaminated work surfaces increase the potential for worker injury or illness, and the spread of contamination throughout the laboratory. Laboratory benchtops, floors, and walls should be constructed of a smooth material that is easy to clean. The material must be resistant to chemical absorption. Good housekeeping practices (e.g., storing chemicals away from work areas) must be promoted at all times. Even the smallest spills must be cleaned immediately, using the appropriate absorbent or neutralizer. A regular schedule of thorough laboratory cleaning should be implemented, basing the schedule on the frequency of use, as well as the types and amounts of chemicals used.

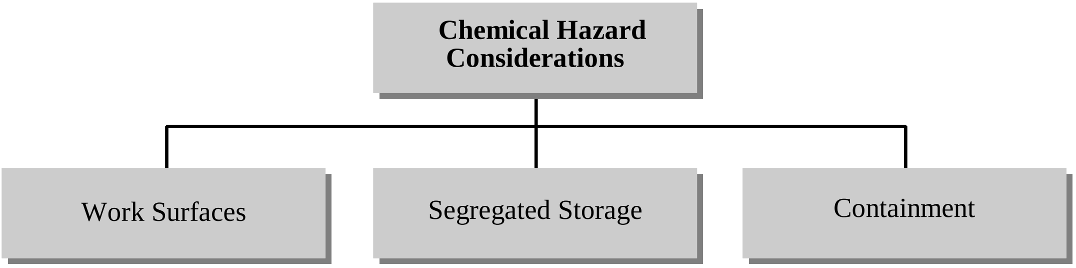
2.2 Segregated Storage

Appropriate storage cabinets should be employed for all chemicals not in immediate use. For OSHA-specific requirements, refer to 29 CFR 1910.106(d)(5). Cabinets must be selected based on the types of chemicals to be stored. Often, ventilated cabinets are available for certain types of chemicals. Outlined below are the types of cabinets to be used for specific groups of chemicals, as well as good work practices and maintenance procedures associated with the cabinets.

2.2.1 Flammables

Examples of flammable materials include, but are not limited to, acetone, ethyl ether, toluene, and methyl formate. Cabinets for flammable chemicals must be:

Figure D5-1: Chemical Hazard Considerations



- Specifically designed to store flammable materials
- Fire resistant
- In compliance with NFPA 30 and OSHA 1910.106 standards
- Designed to protect contents from the heat and flames of external fire (not to confine burning liquids within)
- Designed with double-wall construction and doors which are two inches above the base
- Used and maintained properly

If flammable materials are to be poured or transferred to or from a metal container within the storage area, there may be an accumulation of static charge on the container. The discharge of the static charge could generate a spark, igniting the liquid. Flammable dispensing and receiving containers must be bonded together before pouring. Large containers, such as drums, must also be grounded when used as dispensing or receiving vessels. All grounding and bonding connections must be metal to metal.

Flammable chemicals must never be stored in a standard household refrigerator. There are several ignition sources located inside a standard refrigerator which can set off a fire or violent explosion.

Flammable storage cabinets should be inspected regularly. Chemicals that are not compatible with flammables must never be stored within the cabinet. The cabinets must be kept clean. Leaks and spills must be controlled and cleaned immediately. All chemicals should be readily accessible in the cabinet to avoid spills and breaking containers. Cabinets should never be over-stocked.

2.2.2 Acids/Corrosives

Cabinets for storing acids have similar construction features to a flammable storage cabinet, but they are also coated with an epoxy enamel to guard against chemical attack. They frequently contain polyethylene trays to collect small spills and provide additional protection from corrosion of the shelves. Bases must stored in separate storage cabinets, never with acids. A wooden cabinet is common for storing bases. Common examples of corrosives in EPA laboratories may include sulfuric acid, stannic chloride, and ammonium hydroxide. Nitric acid should have its own storage cabinet by itself. Hydrofluoric acid (HF) must never be stored in a glass container, as these materials are incompatible. HF should also have its own separate storage cabinet. Corrosive material cabinets must never be situated above eye level. Spills and breaks could lead to serious eye and facial injury.

To promote safe storage of corrosives, materials should be purchased in containers that are coated with a protective plastic film to minimize the danger if dropped or tipped. Corrosives should also never be purchased in amounts more than necessary in the laboratory.

Cabinets used for storing corrosives must also undergo regular inspection. Incompatibles must be removed and separated. Cabinets must be kept clean and free from leaks and spills. Shelves and supports must be periodically inspected for corrosion. If corrosion is detected the cabinet must be replaced immediately. Chemicals must be readily accessible and never over-stocked.

2.2.3 Oxidizers

Oxidizers, which include peroxides, chlorates, nitrates, perchlorates, and others, present fire and explosion hazards on contact with combustible materials (oxidizers are also typically corrosive). Oxidizers must be stored away from flammables, organics, and all combustible materials. Strong oxidizing agents, such as chromic acid, must be stored in glass or other inert container that is unbreakable. Corks and rubber stoppers should not be used, as they may “pop” open and explode or spill.

Perchloric acid is of particular concern. Hazards increase with an increase in temperature and concentration. It must be stored away from heat, and may be stored in a perchloric acid fume hood. Where possible, substitutes for perchloric acid should be used to eliminate its presence in the laboratory. Only the amount necessary for work should be kept on-site.

Inspections of storage areas for oxidizers must be performed on a regular basis. The primary focus of inspections should be container stability, cleanliness of storage areas, and the potential for spills and leaks.

2.2.4 Reactives

Water-reactive materials must be stored in an isolated part of the laboratory. A cabinet far-removed from any water sources, such as sinks, emergency showers and chillers, is the most appropriate location. The cabinet must be labeled, “Water-Reactive Chemicals-No Water.” Pyrophorics must also be isolated within the labora-tory. The cabinet must be clearly marked. Peroxide-forming materials must be stored away from heat, sunlight, and sources of ignition to prevent the acceleration of peroxide formation. They must also never be stored in glass containers with screw cap lids or glass stoppers. Friction and grinding must be avoided.

The integrity of containers used for reactives must be inspected regularly. If the container is corroded or otherwise damaged, the material should be disposed of in the appropriate manner. Storage areas must also be regularly inspected for cleanliness, spills, and leaks.

2.2.5 Chemical Waste

Chemical and/or hazardous waste must be stored in containers designed for the accumulation of such waste. Containers must be in good condition, free of leaks, and compatible with the waste being stored within. The container should be opened only when necessary to add waste, and otherwise should always be capped. Hazardous waste storage containers holding waste that is incompatible with any waste or other materials stored nearby must be separated by means of a partition, wall, or other secondary containment device. Caps should be non-leaking screw-on caps.

Additional information on the storage of hazardous waste can be found in Chapter C14.

2.3 Containment

Barrier systems for laboratories will depend on the functions and activities to be performed within the laboratory. Some systems may be designed to contain hazardous agents and prevent accidental releases, while others are designed to exclude contaminating agents that could compromise an experiment. Others may both confine and exclude. These objectives are achieved through a combination of design features, operating procedures, specialized safety equipment, and contamination control systems. Table D5-1 presents the three levels of containment, what they protect, and how they are achieved.

Laboratory waste must be provided with an isolated, exhausted, secured storage area. An interim storage area should be immediately accessible to the "dirty" side of the barrier facility. For animal waste, a cage dump station exhausted to the outside must be located where animal cages are dumped prior to washing.

Walls of diked areas must be made of earth, steel, concrete, or solid masonry and must be liquid tight. Walls and ceilings should be flat and monolithic, with lighting recessed to minimize places where dust may accumulate. All wall, floor, and ceiling penetrations should be carefully sealed to contain the spread of fire and to preserve separation between adjacent areas. Additional information on drains, dikes, and walls can be found in 29 CFR 1910.106. Containment areas should

Table D5-1: Levels of Containment

Levels of Containment
Primary Containment Level • Protects laboratory personnel and the environment from direct exposure to hazardous materials • Provided by engineering controls such as laboratory fume hoods and biological safety cabinets, with the exhaust air filtered or treated to remove the contaminants before discharge
Secondary Containment Level • Protects areas outside the laboratory • Provided by the physical characteristics of the laboratory (e.g., corridor and room construction and arrangement, airlocks, ventilation systems, clothing change rooms, and showers)
Tertiary Containment Level • Protects an entire area or facility • Provided by isolation or physical separation

undergo a regular inspection focusing on the condition of the barrier, as well as leaks and spills within the barrier. All barrier systems must be kept clean and well-maintained.

3.0 Biological Hazards

Detailed information on the control of biological hazards is included in Chapter C7 of this manual. Presented here is general information on containers and other devices used to control biological hazards.

Engineering controls must be the primary source of controlling biological hazards. For any contaminated needles and/or other sharps, mechanical devices specified for such purpose must be used for bending, recapping, or needle removal, where necessary. This practice should be avoided where feasible.

Containers for sharps must be puncture resistant, leakproof on at least the sides and bottom, and labeled or color-coded for identification. Blood and other potentially infectious materials must be placed in a container that prevents leakage and that is also labeled or color-coded. If outside contamination of the primary container occurs, a secondary container must be used to prevent leakage. A secondary container should also be used if the specimen may puncture the primary container. Decontamination of all engineering controls must take place after each use.

Engineering controls for biological hazards must be examined and maintained on a regular basis to ensure their effectiveness. Examination should focus on the integrity of storage containers and other containment devices.

4.0 Radiation Hazards

Engineering controls for radiation safety are design features or devices that are used to minimize radiation hazards to employees and the environment. This section provides examples of radiation safety engineering controls for several types of equipment that may be found in an EPA laboratory (e.g., lasers, accelerators, x-ray machines). Refer to Chapter C6 of this manual for more information on radiation safety.

4.1 Lasers

Engineering controls for lasers can include beam housings, beam shutters, attenuators and remote firing controls. Control measures are determined by the laser class. Table D5-2 presents information extracted from ANSI Z136.1-1993 pertaining to engineering controls according to laser class.

The following sections describe some of these engineering controls.

Protective Housing. A laser shall have an enclosure around it that limits access to the beam or radiation at or below the maximum permissible exposure (MPE) level. Housing is required for all classes of lasers except at the beam aperture. In some cases, the walls of a properly enclosed room can be considered a "walk-in" enclosure that serves as protective housing for an open-beam laser.

Table D5-2: Engineering Control Measures by Laser Class

Engineering Control Measure	**Laser Classification**				
	I	II	IIIa	IIIb	IV
Protective housing	MUST	MUST	MUST	MUST	MUST
Interlocks on housing	ENCL	ENCL	ENCL	MUST	MUST
Service access panel restriction	ENCL	ENCL	ENCL	MUST	MUST
Master switch control	NR	NR	NR	REC	MUST
Optical viewing portals	NR	>MPE	>MPE	>MPE	>MPE
Collecting optics below MPE	>MPE	>MPE	>MPE	>MPE	>MPE
Totally or partially open beam path	NR	NR	NR	NHZ	NHZ
Interlock	NR	NR	NR	REC	MUST
Beam stop/attenuator	NR	NR	NR	REC	MUST
Activation warning	NR	NR	NR	REC	MUST
Beam emission delay	NR	NR	NR	NR	MUST
Indoor/outdoor controlled area	NR	NR	NR	NHZ	NHZ
Navigable airspace	NR	NR	REC	REC	REC
Temporary controlled area	ENCL or >MPE	ENCL or >MPE	ENCL or >MPE	NR	NR
Remote firing/monitoring	NR	NR	NR	NR	REC
Labels	MUST	MUST	MUST	MUST	MUST
Posting of signs	NR	NR	REC	NHZ	NHZ

This table shows that there are controls that are:

- Required based on the laser class (MUST)
- Not required for the laser class (NR)
- Required if the maximum permissible exposure is exceeded (>MPE)
- Required in addition to establishing a nominal hazard zone (NHZ)
  Required if the laser is an enclosed Class IIIb or IV (ENCL)
- Recommended based on the laser class (REC)

Master Switch Control. All Class IV lasers and laser systems require a master switch control. The switch can be operated by a key or computer code. When disabled, the laser cannot be operated. Only authorized system operators are to be permitted access to the key or code.

Optical Viewing System Safety. Interlocks, filters, or attenuators are to be incorporated in conjunction with beam shutters when optical viewing systems such as telescopes, microscopes, viewing ports, or screens are used to view the beam or beam-reflection area. For example, an electrical interlock could prevent laser system operation when a beam shutter is removed from the optical system viewing path. Such optical filter interlocks are required for all except Class I lasers.

Beam Stop or Attenuator. Class IV lasers require a permanently attached beam stop or attenuator which can reduce the output emission to a level at or below the appropriate MPE level when the laser system is on "standby." Such a beam stop or attenuator is also recommended for Class IIIa and Class IIIb lasers.

Laser Activation Warning System. An audible tone or bell and/or visual warning such as a flashing light is recommended as an area control for Class IIIb laser operation. Such a warning system is mandatory for Class IV lasers. These systems are required to be activated upon system start-up and are to be uniquely identified with the laser operation. Verbal countdown commands are an acceptable audible warning and should be part of the standard operating procedure.

Service Access Panels. The ANSI Z136.1 standard requires that any portion of the protective housing that permits direct access to an embedded Class IIIb or Class IV laser must have either an interlock or require a tool in the removal process. If an interlock is used and is defeatable, a warning label indicating this fact is required on the housing near the interlock. The design shall not allow replacement of a removed panel with the interlock in the defeated condition.

Protective Housing Intelock Requirements. Interlocks that cause beam termination or reduction of the beam to MPE levels must be provided on all panels intended to be opened during operation and maintenance of all Class IIIa, Class IIIb and Class IV lasers. The interlocks are typically electrically connected to a beam shutter. The removal or displacement of the panel closes the shutter and eliminates the possibility of hazardous exposures.

Remote Interlock Connector. All Class IV lasers or laser systems must have a remote interlock connector to allow electrical connections to an emergency master disconnect interlock or to room, door or fixture interlocks. When open circuited, the interlock shall cause the accessible laser radiation to be maintained below the appropriate MPE level. The remote interlock connector is also recommended for Class IIIb lasers.

In some cases, such as during research and development, the operation of an unenclosed laser or laser system may be necessary. In such cases, the laser safety officer must determine the hazard and ensure that controls are instituted appropriate to the class of maximum accessible emission to ensure safe operation. Such controls may include:

- Access restriction
- Eye protection
- Area controls
- Barriers, shrouds, beam stops, etc.
- Administrative and procedural controls
- Education and training

4.2 Accelerators

Particle accelerators must be installed with primary and secondary barriers that are necessary to ensure that exposures are minimized. Instrumentation, readouts and controls on the accelerator control console should be clearly identified and easily discernable. The accelerator area can be equipped with an easily observable flashing, rotating warning light that operates when radiation is being produced. A radiation survey should be conducted to determine compliance with exposure limits as discussed in Chapter C6 of this manual.

4.3 X-Ray Equipment and Radiation Generating Devices

Analytical x-ray equipment and radiation generating devices should be equipped with engineering controls as follows:

Safety Devices. Devices that prevent the entry of any portion of an individual's body into the primary x-ray beam path or which causes the beam to be shut off upon entry into its path must be provided on all open-beam configurations.

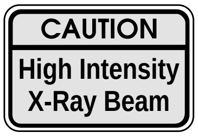
Warning Devices. Open-beam configurations must be labeled so that their purpose is easily identified, and have fail-safe characteristics. In addition, they should be provided with a readily discernible indication of:

- *X-ray tube status* - whether the tube is on or off; located near the radiation source housing, if the primary beam is controlled in this manner

- *Shutter status* - whether the shutter is open or closed; located near each port on the radiation source housing, if the primary beam is controlled in this manner

Ports. Unused ports on radiation machine source housings must be secured in the closed position in a manner which will prevent casual opening.

Labeling. All analytical x-ray equipment must be labeled with a readily discernible sign or signs such as:



Shutters. On open-beam configurations, each port on the radiation source housing shall be equipped with a shutter that cannot be opened unless a collimator or a coupling has been connected to the port.

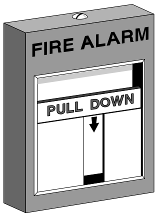
Warning Lights. An easily visible warning light labeled with the words "X-RAY ON" shall be located near any switch that energizes x-ray tube and must be illuminated only when the tube is energized. Warning lights must have fail-safe characteristics.

5.0 Fire Hazards

Control and prevention of fires in a laboratory involve the use of the following engineering controls, as outlined in the sections below:

- Alarm systems
- Protection systems
- Fire extinguishers

5.1 Alarm Systems



An integral component of an Emergency Action Plan (refer to Chapter G of this manual) is a reliable, well-designed employee alarm system. Each EPA laboratory must be equipped with an employee alarm system that complies with OSHA's standard on employee alarms (29 CFR 1910. 165). The system must:

- Provide warning for necessary emergency action or for reaction time for safe evacuation of employees from the workplace

- Be perceived above ambient noise or light levels by all employees in the affected portions of the laboratory

- Be distinctive and recognizable as a signal to evacuate the work area or to perform designated actions

The laboratory must ensure that all devices, components, and systems installed as part of the employee alarm system are approved, maintained, and regularly tested.

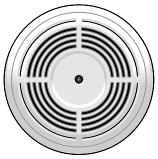
5.2 Protection Systems

Protection systems are used at EPA laboratories to protect employees, as well as the facility in a fire. This section describes requirements for detection systems, automatic sprinkler systems, and other extinguishing systems.

5.2.1 Detection Systems

Detection systems are used at EPA laboratories to identify conditions that could lead to fire and/or explosion, or the early stages of a fire. Detection systems are also used to detect releases of harmful chemicals or other hazardous materials. There are four types of detection systems often used in facilities to protect against fire hazards:

Heat Detectors: These devices respond to the convected thermal energy of a fire. They are activated when the detecting element reaches a predetermined fixed temperature, or when a specified rate of temperature change occurs. The former are called fixed-temperature detectors; the latter are rate-of-rise detectors. Some detectors combine both features.



Smoke Detectors: Ionization smoke detectors typically respond faster than the photoelectrictype to flaming fires, as these fires produce smaller smoke particles. The larger smoke particles that are generated by smoldering fires are typically detected faster by photoelectric detectors.

Flame Detectors**:** These detectors respond to radiant energy from flames, coals or embers. There are two types: infrared and ultraviolet flame detectors. The major difference is the insensitivity of the latter to sunlight.

***Combustible Gas Detectors*:** These units detect the presence of flammable vapors and gases. They are used to warn when concentrations of these vapors in the air approach the explosive range.

Toxic Gas Detectors: This instrumentation can be used for detecting both major releases and small leaks of toxic materials so that the proper response action can be initiated at the earliest time.

5.2.2 Detector Selection and Installation

The selection of a detector should be based on the anticipated hazard(s) and the environment to be protected. Criteria include:
- Type and amount of combustibles
- Possible hazard sources
- Environmental conditions
- Property values

Heat Detectors: Heat detectors are used most effectively to protect confined spaces, or the areas immediately next to a particular hazard. Because the heat from a fire can dissipate quite rapidly over a larger area, further propagation of fire is required before the device is tripped. The operating temperature of a heat detector is typically 25 degrees higher than maximum ambient conditions.

Smoke Detectors: These detectors typically respond more quickly to fire than heat detectors, and can be used effectively in large, open spaces. Photoelectric devices are preferable if smoldering fires are anticipated, while ionization devices are more effective at detecting flaming fires. Prevailing air currents, as well as ceiling and room configurations, are a key consideration in their placement.

Flame detectors: Flame detectors are generally installed in high-hazard areas where rapid fire detection is critical. However, infrared flame detectors are subjected to interference from solar radiation, so the potential for false trips is important. Since flame detectors are line-of-sight devices, an unobstructed view of the flame must occur for detection.

Combustible Gas Detectors: These detectors are selected and calibrated for the specific substances to be detected. They are typically located close to the hazard and are set to activate an alarm when a certain percent of the lower flammable limit is reached.

Additional details on selection and installation of automatic fire detectors can be found in NFPA No. 72, “National Fire Alarm Code.”

Toxic Gas Detectors: Toxic gas detectors are selected based on considerations such as sensitivities, speed of response, substance to be detected, and sampling mode.

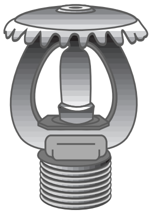
Additional details on selection and installation can be found in *Guidelines for Postrelease Mitigation Technology in the Chemical Process Industry* published by the Center for Chemical Process Safety.

Testing and Maintenance

Testing and maintenance of detection systems and their components are keys to reliable operation. These activities also help reduce the number of false alarms. Such actions should be performed on a regular basis and documented for review.

5.2.3 Automatic Sprinkler Systems

The following information is presented as reference material for personnel at laboratories which have, or are considering the installation of, such systems.



Types

Sprinkler systems automatically provide water to extinguish fires. The different types of systems available include:

- *Wet pipe systems*: These are characterized by the presence of water in the lines under pressure. The water will flow through any head(s) that fuses in a fire environment.
- *Dry pipe systems*: These are characterized by the presence of air in the lines under pressure. The air will flow through any head(s) that fuses in a fire environment. This allows water to flow into the lines. Water then flows through the fused head(s).
- *Preaction systems*: These have air in the lines, and have a fire detection system. The detection system operates a valve that allows water to flow into the lines. The system then operates like a traditional sprinkler system.

Water Supply Requirements

While there are various sprinkler system designs, a critical characteristic of all systems is the design density. Design density is expressed in gallons per minute per square foot (gpm/ft^2) over an area of sprinkler operation. The design density required for adequate fire protection of a laboratory depends upon the fire loading of combustibles, and may vary from room to room. The design density provided by the sprinkler system is a function of head spacing, pipe scheduling, and water supply. Thus, the design density required by the laboratory and the design density provided by the sprinkler system are both important considerations.

In considering water supply requirements, data on the static pressure (psi) and the residual pressure (psi) when water is flowing (gpm) are important. Allowance must also be made for the demand of hose streams, typically 250 gpm, in anticipation of possible manual fire-fighting efforts.

Additional details on the design and installation of automatic sprinkler systems can be found in the NFPA No. 13, “Sprinkler Systems.”

Inspection and Maintenance

Inspection and maintenance are critical to the reliability of sprinkler system operation. Items to be inspected include the sprinkler control valves, the water pressure, and (in the case of dry systems), the air pressure. Fire pumps and suction tanks should also be checked if they are system components. Sprinkler system maintenance should address head condition, corrosion, and freezing. Periodic flushing of yard mains and branch lines will help ensure reliable water flow. More specific maintenance items are a function of system design (e.g., annual trip testing for dry pipe valves).

5.2.4 Other Extinguishing Systems

The following information is presented as reference material for personnel at laboratories which have, or are considering the installation of, such systems.

When selecting or evaluating automatic extinguishing systems, the nature of the area to be protected must be understood. There are four basic types of fires, all of which can occur in the laboratory environment:

Class A: Fires in ordinary combustible materials, such as wood, cloth, paper, rubber, and some plastics

Class B: Fires in flammable liquids, oils, greases, tars, oil base paints, lacquers, and flammable gases

Class C: Fires that are engendered by energized electrical equipment

Class D: Fires in combustible metals, such as magnesium, titanium, zirconium, sodium, lithium, and potassium

Dry Chemical Systems

Dry chemicals are powders that are effective in extinguishing Class A, B, and/or C fires. Advantages of using this type of automatic extinguishing system include quick knockdown capability and nonconductivity; however, disadvantages include slight corrosivity and difficulty in clean-up.

A fixed dry chemical system consists of the agent, an expellant gas, a means to activate the system (e.g., a flame detector), and fixed piping and nozzles. Designs include both total-flooding and local-application types. Additional details on the design and installation of fixed dry chemical systems can be found in NFPA No. 17, "Dry Chemical Extinguishing Systems."

Carbon Dioxide Systems

Carbon dioxide is effective in extinguishing Class B and C fires. Extinguishment is accomplished by reducing the oxygen content of the atmosphere, so it no longer supports combustion. It can also extinguish a fire by cooling. Advantages of this type of extinguishing system include its own pressure for discharge and the lack of residue after use. Disadvantages, however, include the need for retention of the extinguishing atmosphere, and the inherent danger of oxygen displacement when used in areas occupied by personnel.

A carbon dioxide system consists of the agent, a means to activate the system (e.g., heat detector), and fixed piping and nozzles. Designs include both total flooding and local application types. Although enclosure is mandatory for total flooding, it is strongly recommended for local applications. Additional details on the design and installation of carbon dioxide systems can be found in NFPA No. 12, "Carbon Dioxide Extinguishing Systems."

Foam Systems

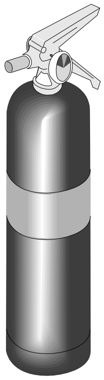
There are several different types of foams used to suppress fires and/or vapors from flammable or combustible chemicals. Foams are defined by their expansion ratio, or their final foam volume compared to their original foam solution volume before adding air. There are:

- Low-expansion (<20:1)
- Medium-expansion (20-200:1)
- High-expansion (200-1,000:1)

Different foaming agents include aqueous film-forming foam, fluoroprotein foam, alcohol-type foam, and high-expansion foam. Application can be effected via fixed or portable systems.

Additional details on the design and installation of foam systems can be found in NFPA No. 11, “Low Expansion Foam Systems” and NFPA No. 11A, “Medium and High Expansion Foam Systems.”

5.3 Fire Extinguishers



Hand portable fire extinguishers are considered to be the first line of fire defense. They represent the most mobile equipment available and are used primarily to suppress small, accessible fires before those fires have the opportunity to grow in size and intensity. This section provides information on the types of extinguishers, their location and installation, proper use, inspection, testing and maintenance, and training.

5.3.1 Types of Extinguishers

The selection of fire extinguisher type should be based on the class of hazards to be protected:

Class A hazards should be protected with water, multipurpose dry chemical, and foam or aqueous film-forming foam (AFFF).

Class B hazards should be protected with dry chemical, carbon dioxide, foam or AFFF.

Class C hazards should be protected with dry chemical or carbon dioxide.

Class D hazards should be protected with extinguishers and extinguishing agents approved for use on the specific combustible metal hazard (e.g., G-1 powder for magnesium fires, Lith-X for lithium fires).

For the majority of research laboratory applications, water and AFFF extinguishers should have a capacity of 2.5 gallons. Dry chemical, carbon dioxide, and foam extinguishers should hold 20 to 30 pounds. In site selection, one should consider both the hazards and the strength of the personnel using the extinguisher.

Historically, bromochlorodifluoromethane (Halon 1200) and bromotrifluoromethane (Halon 1301) extinguishers have been recommended for use on certain types of fires. In light of the ozone layer depletion and the resulting Montreal Protocol that set a goal of halving the use of chlorofluorocarbons by the end of the nineties, halon use is decreasing and is not recommended.

5.3.2 Location and Installation

Fire extinguishers should be located *conspicuously* and br readily accessible in the event of a fire. There should be a maximum travel distance of 30 feet to an extinguisher, and it should be located along normal paths of travel, including exits from an area. Preferably, extinguishers should be located close to any known hazard. In addition, the top of the extinguisher should be installed no more than five feet above the floor, and the clearance between the bottom of the extinguisher and the floor should be no less than four inches. Finally, operating instructions should be placed on the front of the extinguisher, where they can be easily seen.

5.3.3 Extinguisher Use

The acronym "PASS" represents the following procedure, which should be observed after selecting the correct fire extinguisher and readying it for use.

PULL out the locking pin and the plastic seal or push the activator

AIM the nozzle at the base of the fire

SQUEEZE the release trigger

SWEEP the extinguishing material across the base of the fire from side to side

In addition, the following should be noted for fighting fires:
- When approaching a fire, be sure you can retreat rapidly in a straight line.
- Never turn your back on a fire or the place where the fire was just burning.
- Never use water on combustible metals, flammable liquids, or on electrical fires while the current is on.
- Keep the wind at your back to avoid flashback.

5.3.4 Inspection, Testing and Maintenance

Inspections of fire extinguishers should be conducted regularly (at least monthly) to ensure that they have been properly placed and are operable. It is also important that each inspection be documented, with records retained, for review.

Staff performing routine inspections should check that each extinguisher:

- Is in its designated place
- Is conspicuous
- Is not blocked in any way
- Has not been activated and become partially or completely emptied
- Has not been tampered with
- Has not sustained any obvious physical damage or been subjected to an environment that could interfere with its operations (e.g,. corrosive fumes)
- Shows satisfactory condition, if equipped with a pressure gauge and/or tamper indicators

Maintenance of extinguishers involves a complete and thorough examination. It should include examining the mechanical parts, the amount and condition of the extinguishing agent, and the condition of the agent's expelling device. Maintenance techniques vary for each extinguisher, and inspections should be performed by qualified personnel. Formal maintenance activities should be conducted at least yearly.

In addition to routine maintenance, hydrostatic testing must be performed on extinguishers subject to internal pressures to protect against failure caused by the following:

- Internal corrosion from moisture
- External corrosion from atmospheric humidity or corrosive vapors
- Damage from rough handling
- Repeated pressurizations
- Manufacturing flaws
- Improper assembly of valves or safety relief discs
- Exposure to abnormal heat, such as fire

Hydrostatic tests should be conducted by qualified personnel using proper equipment. Such tests are often performed by firms that sell and service fire extinguishers. A recommended schedule for hydrostatic testing is five years for water, dry chemical, carbon dioxide, foam, and aqueous film-forming foam extinguishers, as stipulated in 29 CFR 1910.157 and NFPA No. 10.

Tags and seals should be used to record inspection and maintenance checks. (A seal is a good indicator of whether an extinguisher has been used.) In addition, a record should be kept of the date of purchase and dates of maintenance for each extinguisher. For maintenance, recharging, and hydrostatic tests, records should include the date of testing, and the name of the person or agency who performed the test. For hydrostatic tests, the record should also include a description of dents that remained after passing a hydrostatic test.

6.0 Noise

Loud noise levels in laboratories are typically attributed to ventilation equipment and laboratory animals. Noise levels must stay below 85 decibels (dBA) for an 8-hour time-weighted-average (TWA) in work areas, otherwise a hearing conservation program must be implemented. Levels this loud through, are not common in laboratories. Engineering control techniques must be the primary means of controlling noise exposures above 85 dBA, and are often applied to control levels lower than this for an even more comfortable range. For the application of engineering noise controls, a professional engineer or experienced industrial hygienist should be consulted.

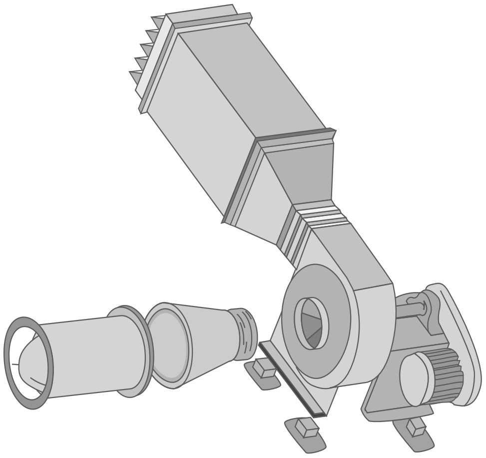
6.1 Ventilation Equipment Noise

The American National Standard for Laboratory Ventilation (ANSI/AIHA Z9.5-1992) states that fans, ductwork, and air velocities of laboratory ventilation equipment must not exceed 85 dBA at laboratory work locations. Fans must be located or provided with noise treatment to maintain levels below this limit at any frequently occupied work station. The system must be designed to provide control of exhaust system noise in the laboratory.

The types of fans used for laboratory hood exhaust are flat blade and backwardly-curved-blade centrifugal fans, in-line centrifugal fans, and vane axial fans. If possible, increased sound levels due to new installations of fans and/or other ventilating equipment should be calculated in advance. Then, noise may be controlled by selection and design.

The fundamental controls of centrifugal fan noise include the utilization of absorptive, parallel, or circular baffle-type silencers. This type of silencer has good high-frequency attenuation and minimal aerodynamic pressure loss (not likely to affect fan efficacy). Figure D5-2 illustrates a simple, common approach. A tubular silencer is installed on the inlet of the fan using an adapter, and a parallel baffle duct-type silencer is installed on the exhaust. A flexible coupling of dense material adapts the silencers to the fan and provides vibration isolation between the fan and the ductwork. Vibration mounts are used to isolate the fan from the duct system.

Figure D5-2: Centrifugal Fan Silencer



For axial fans, the basic approach of installing a tubular absorptive silencer on the inlet and exhaust is used for noise control. Figure D5-3 demonstrates this approach for axial fans. Also, the fan should be isolated from the ductwork, floor, ceiling, and/or platform. To select a silencer, use the following method:

- Calculate the volume flow or face velocity, and compare it to the silencer manufacturer's pressure loss specifications.

- Size the silencer so the open flow-through cross section is 1.25 to 1.5 times the fan duct cross-sectional area.

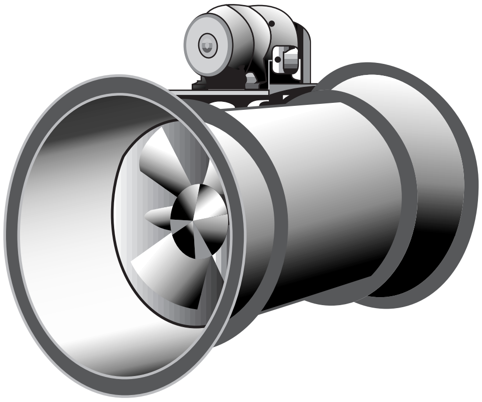
In office buildings, a common approach to control noise associated with ventilating equipment is to line ductwork with absorptive material. This method must *never* be applied to laboratory ventilation equipment. Materials used to absorb noise will also absorb chemicals, preventing air-stream cleaning. The materials are also typically combustible, promoting a fire within the ductwork upon contact with certain chemicals.

6.2 Animal Noise Control

Laboratory animals, as well as the associated support functions such as cage-washing, may create a high level of noise within a laboratory. The noise is not only harmful to human workers, but to the animals themselves. Masonry walls are a good source of noise control, as opposed to metal or plaster. The density of the masonry walls reduces the transmission of noise through the walls. The use of acoustic materials for noise absorption on the ceilings is not recommended, as this could present sanitation problems. Sanitizable sound-attenuating materials bonded to walls or ceilings can be applied for noise control, as appropriate. Again, a professional must be consulted to determine the applicability and effectiveness of such control techniques. Other general noise control methods used to prevent transmission down corridors include:

- Well-constructed corridor doors
- Sound-attenuating doors
- Double-door entry

Figure D5-3: Axial Fan Silencer



For the protection of laboratory animals, fire and environmental-monitoring alarm systems and public-address systems should be selected and located to minimize potential exposure to animals. Many species can discriminate much higher frequencies than humans, so it is important to consider the location of equipment, avoiding the generation of ultrasonic frequency sound.

7.0 Laboratory Illumination

Proper laboratory illumination not only increases the quality of the work environment, but also:

- Improves worker morale
- Reduces the potential for accidents
- Improves laboratory housekeeping

This section describes some general provisions for the design of laboratory lighting, required lighting levels for EPA laboratories, and a basic description of lighting level measurements.

7.1 Design of Lighting Systems

An illumination engineer should be consulted for installation of new lighting systems, or for any major laboratory redesign. Adequate quantity and quality of light are essential considerations in the design process. The quantity of light needed within the laboratory will be different based on different tasks performed within the laboratory. For example, work performed inside a laboratory hood will typically require a greater quantity of light than tasks performed in storage areas, based simply on the inherent characteristics of tasks performed in these two types of areas. Glare, contrast, and color are important quality considerations. Laboratory personnel should be consulted about the scale of the tasks they perform, and the types of equipment (e.g., size, color, etc.) they use. Lighting systems are then designed based on this information. The physical characteristics of the room and the desired appearance of the finished installation are considerations as well.

Localized lighting systems should be installed where high light intensity is needed (i.e., specialty-seeing critical tasks). Localized lighting systems are also useful where a directional quality is needed. When installing a localized lighting system, caution must be taken to ensure a reasonable relationship between intensities of the general and of the localized lighting. An excessive luminance ratio between the work point and the surroundings will create an uncomfortable seeing condition.

Other factors to consider in the design of a lighting system include:

- Choice of light source (i.e., filament, mercury vapor, fluorescent)
- Heat produced from the source
- Efficiency of the lamp or light source
- Electrical features (e.g., type of wiring)
- Mechanical structure of the support of the fixtures
- Appearance/decoration

It is important to note that the types of hazards and chemicals present in the laboratory may affect the choice and design of lighting systems. For example, flammable storage areas should be designed with explosion-proof lighting systems.

7.2 Illumination Requirements and Recommendations

The EPA's *Facility Safety, Health, and Environmental Management Manual* dictates that work-area lighting must be maintained, as near as practical, to the recommendations of the Illuminating Engineering Society of North America, in their handbook entitled *Recommended Practices*. Guidelines established in 41 CFR 101-20 (Federal Property Management Regulations) and the General Services Administration's (GSA) Public Buildings Service (PBS) PX100-1 must also be followed where possible. In these guidance documents, the following lighting levels in Table D5-3 are generally recommended:

All ultraviolet lights installed for scientific operations must be evaluated for safety on a case-by-case basis. Shielding and interlocks must be provided where appropriate.

Within laboratories, the following recommendations should be considered:

Laboratory Working and Storage Areas	50 foot-candles
Bench-Top Work Surfaces	100-1000 foot-candles
Work Surface Under Hoods	100-1000 foot-candles
Interior Corridors	30 foot-candles

7.3 Measurement of Light

Illumination is measured in foot-candles, which is actually a measurement of light density. To measure light, there are many types of foot-candle meters available. Typical meters are portable, with a wide range of sensitivity. The type of meter chosen is based on the areas monitored and desired accuracy of results. Careful handling and frequent calibration is necessary with most foot-candle meters to maintain reliability. Ordinary field measurements cannot be expected to have an accuracy greater than ±5% under the most favorable conditions. In addition, the user must understand the following meter characteristics to obtain the best possible results:

- The instrument must be color corrected, due to the difference between instrument sensitivity and that of the human eye

- The instrument must be adjusted for the angle of the reflected light

Table D5-3: Recommended Lighting Levels

Levels	Work Location	Measurement Location
50 to 100-foot levels	Laboratory spaces	At bench level
50 foot candles	General office areas	30 inches above floor level
30 foot candles	Other work areas	30 inches above floor level
5 to 10-foot candles	Corridors and stairways	At walking surface

- The light-sensitive cells of the instrument will exhibit fatigue (tendency for the meter indication to drop off slowly over a period of minutes until a constant reading is reached). This effect is predominant at high foot-candle levels, especially if the meter was recently taken from a dark storage location. The meter must be given an adaption period, and must experience constant calibration.

The owner’s manual for foot-candle meters must be consulted on the particular techniques used for the specific meter, to obtain the best possible results.

To perform a lighting survey, the following information must be obtained:

- Description of the illuminated area
  - — Room dimensions
  - — Color
  - — Reflectance
  - — Conditions of the room surface
  - — Temperature surrounding the lights

- Description of the general lighting system
  - — Quantities
  - — Conditions
  - — Wattages
  - — Lamps
  - — Distribution
  - — Spacings
  - — Mountings

- Description of any supplementary lighting that might be used

- Description of instruments to be used
  - — Illumination measurement
  - — Do not cast shadows
  - — Do not reflect additional light from clothing
  - — Test surfaces as close to the working plane as possible (if no working plane, take measurements on a horizontal plane 30 inches above the floor)

- Luminance measurements

The data resulting from the light survey can be used to compare the illumination levels for compliance with EPA-required levels. Results may also be used to determine:

- Luminance ratios for visibility and safety
- Comfort level and pleasantness in the area
- Lighting deficiencies
- A light-system maintenance schedule