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Laboratory Design; Approved Guideline

This document provides a foundation of information about laboratory design elements to help define the issues to be considered when designing a laboratory.

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Laboratory Design; Approved Guideline

Abstract

Laboratory Design; Approved Guideline (NCCLS document GP18-A) is written for laboratory personnel responsible for, or involved in, the design of a laboratory. This guideline addresses selected nonstructural elements that affect laboratory effectiveness and safety. The elements addressed include space, casework and furniture, storage, ventilation, lighting, and fresh and waste water.

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Pennell C. Painter, Ph.D., F.A.C.B., Chairholder
Anne C. Belanger, M.A., M.T.(ASCP)
Carl H. Blank, Dr.P.H.
Arthur G. Garikes, A.I.A.
Karen K. Mortland, M. Arch., M.T.(ASCP)

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Anne C. Belanger, M.A., M.T.(ASCP)	Joint Commission on Accreditation of Healthcare Organizations Oakbrook Terrace, Illinois
Carl H. Blank, Dr.P.H.	Wyoming Department of Health Cheyenne, Wyoming
Arthur G. Garikes, A.I.A	Garikes Wilson Karlsberger Birmingham, Alabama
Karen K. Mortland, M. Arch., M.T.(ASCP)	Burt Hill Kosar Rittelmann Associates Butler, Pennsylvania

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Jill E. Clarridge, Ph.D.	VA Medical Center Houston, Texas
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C. Ann Hawthorne	FDA Center for Devices/Radiological Health Rockville, Maryland
Sandra S. Heatherly, M.T.(ASCP), MPH	Baptist Medical Center of Oklahoma Oklahoma City, Oklahoma
Joan Jensen	Mercy Hospital Port Huron, Michigan

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Foreword

Optimal laboratory design requires a careful blending of many design elements, which can be effectively accomplished only if both potential problems and possibilities are well understood. A good understanding of the design issues that affect space, cabinetry, ventilation, lighting, water supply, waste water removal, and storage encourages asking the right questions and facilitates wise choices during reviews of existent laboratories and planning new or remodeled laboratories. Many existent laboratories were designed when the requirements for each of these areas were different than they are today. Thus, it is more important than ever that laboratories are designed so that they can more easily and effectively respond to operational and mission changes.

The advent of robotics and instrument consolidation changes in the future may permit more procedures to be done in less space then is possible today, provided the laboratory is designed to permit the flexible changes that will be required to accommodate those innovations. During future revisions of this guideline, the Area Committee on General Laboratory Practices will seek advice from the Area Committee on Automation on the changes in laboratory design resulting from mechanization. The Area Committee on Automation manages the development of a comprehensive set of standards and guidelines that address, in a prospective manner, the design, compatibility, and integration of automated clinical laboratory systems worldwide.

NCCLS document GP18-A—*Laboratory Design; Approved Guideline* provides a foundation of information about laboratory design elements that can be used to help define the issues to be considered when designing a laboratory.

The content and organization of GP18-A is intended to encourage its frequent use throughout the laboratory-design process. One aspect of this document that distinguishes it from other publications on laboratory design is that, where possible, specific minimum and recommended guidelines are given. The minimum limits are set at the point where laboratory safety or functionality begins to be compromised. Recommended guidelines are set at points where more acceptable levels of safety and functionality are attained.

The NCCLS Subcommittee on Laboratory Design looks forward to your comments and suggestions on the utility of this guideline. Particularly helpful would be suggestions relating to new innovations such as robotics or automation that should be included in the next revision of this guideline. All comments and suggestions will be considered during the revision process that precedes moving the guideline to the next consensus level, and responses to each will be provided in an appendix to the revised guideline.

Key Words

Laboratory design, laboratory space, laboratory casework, laboratory storage, laboratory ventilation, laboratory lighting, fresh water, waste water.

Laboratory Design; Approved Guideline

1 Introduction

Finding the professionals who may be able to contribute to informed decision making about laboratory design issues can be difficult. Without an adequate exchange of information between these professional resource persons and laboratory personnel, important decisions may be inappropriately left to those who do not work in a laboratory environment. The inability to obtain informed input at critical points in the laboratory design process may result in a final product that the laboratory staff finds less than satisfactory in both form and function.

Often, a seemingly simple project, such as expanding laboratory casework or overhead cabinetry so that more work can be done within a given area, becomes complex. Consideration must be given to whether cabinetry additions will affect the electrical, plumbing (fresh and waste water), and air-handling systems in the laboratory. In some facilities, the cost of bringing these support systems up to appropriate standards becomes a major component of the remodeling project budget. This document provides guidance on, and specific information for, working through labor-atory design issues with architects, planners, and other professionals involved in the overall process of developing a new or remodeled laboratory area.

2 Scope

Laboratory design includes many activities that, when thoughtfully and carefully applied, cul-minate in a well-conceived and highly functional laboratory. This document addresses select, nonstructural elements of laboratory design that affect laboratory effectiveness and safety. These elements include space, case-work and furniture, storage, ventilation, lighting, and fresh and waste water. This document is intended to give general guidance in laboratory design for those working in and managing laboratories. Many specific issues and important considerations that will need to be considered in a well designed laboratory are beyond the scope of this guideline and are best worked through with the project's architect.

3 Space

Allocation and organization of space are among the most controversial issues in laboratory design. Inadequate space is a chronic com-plaint in many laboratories. Indeed, space inadequacies sufficient to present a safety hazard are often cited as deficiencies as a result of inspections of clinical laboratories by accrediting bodies. Inspection agencies and accrediting bodies are concerned about lack of adequate space because crowding and clutter may affect safety, as well as the quality of work performed in the laboratory.

Inadequate working space is a potential cause of laboratory accidents. Space-associated accidents can occur if workers collide with each other or collide with instruments. Over-crowded conditions can result in a worker having to reach for something in an awkward way, which may cause the worker to drop an object, strain a muscle, or experience a fall. Such accidents can affect the health and safety of laboratory personnel and/or the outcome of clinical laboratory testing.

Code, certification, inspection, and standards organizations seldom list specific space require-ments for the clinical laboratory. Instead they use phrases such as ". . . sufficient *space, equipment, and supplies within the pathology and clinical laboratory services to perform the required volume of work with optimal accuracy, precision, efficiency, timeliness, and safety."* GP18-A focuses on those aspects of space that affect safety within the laboratory.

3.1 Quantity

3.1.1 Laboratory Space: Responsibility for Adequacy

Adequacy of space is often determined as much by what is put into the space as by the physical limits of the space itself. Too often, an initially adequate laboratory space becomes progressively dysfunctional over time as more objects are put into that space. Counters and work islands are gradually added, every inch of countertop gradually becomes overcrowded, aisles are narrowed, and pathways are rerouted around added work areas. Finally, inspectors

declare what those working in the laboratory already know: The laboratory is no longer large enough to accommodate both the laboratory personnel and their activities safely. Indeed, some laboratories may contain two to three times the amount of instrumentation, cabinetry, refrigerators/freezers, and personnel as the space, and the electrical and heating/air conditioning service, were originally designed to support.

3.1.2 Cited Space Allocation Criteria

There are too many variables involved to firmly tie the space requirements of a clinical laboratory to work output, number of staff members, or the size of a facility. The fact that technology is permitting fewer persons to do more work in less space may be balanced by a rapid rise in new, high-value, labor-intensive tests. A better method of estimating the amount of space needed is to do a current needs assessment (as shown in Section 3.8) and project future needs from the program statement information generated.

3.2 Quality

3.2.1 Size Appropriateness of Functional Working Space

To minimize the likelihood of laboratory accidents, the amount of functional working space in a clinical laboratory must support the maximum number of persons working in the area at one time, the amount of equipment and test work areas the space must support, and, ultimately, the purpose of the laboratory. It is helpful to divide discussions of adequate space into discussions of functional working space, storage space, and support space.

Both the size and location of a functional working space have a significant effect on laboratory safety, quality of work produced, and the functionality of the laboratory. As used here (see Figure 1), functional working space means the square footage of lateral working and walking surface to which laboratory workers must have access in order to accomplish their assigned tasks. This lateral working and walking space directly converts to square footage of floor space. In the following examples, the person operating the automated clinical chemistry profile analyzer must have access to a minimum of 81 sq ft (7.5 sq m) of floor space. In contrast, the person working at the bench doing a manual radioimmunoassay procedure requires only 22 sq ft (2.0 sq m) of floor space. The size of both spaces is appropriate, and certainly not excessive, given that the operator of the automated analyzer interacts extensively with three different work areas (e.g., the analyzer, the computer workstation, and the sample/clerical work area), while the manual assay is done mostly within one work area. Aisles between functional work spaces, as between analyzers and workbenches, comprise an integral part of the total functional work space, as noted in Figure 1. Consequently, aisle width can have an important effect on laboratory safety.

3.2.2 Storage and Support Space

The size and location of storage and support space have a significant effect on both laboratory functionality and laboratory safety. Storage space includes all under-the-counter, overhead, refrigerated, and freezer storage areas. These are discussed in detail in Section 5. Support space refers to all lateral surface space involved in preanalytic and postanalytic functions. Many of the preanalytic, and nearly all postanalytic, functions in laboratories are now considered clerical in nature and are frequently performed using computer work-stations. As automation has increased the productivity and decreased the space often required for the analytic component, documen-tation and regulations have increased the space and time required for the support tasks. Consideration needs to be given to equipment for clerical tasks, and to waste disposal.

The quality of any space depends on how suitable the space is for the required task. This suitability is affected most by how the space is organized, its location relative to other sections in the laboratory and the facility, and the building's environmental support system. If the lighting and air conditioning are inadequate, if the configuration of the space is compromised by columns and unnecessary walls or partitions, or if one laboratory section is remote from other laboratory sections that it must interact with frequently, the space can be considered unsuitable, regardless of its overall

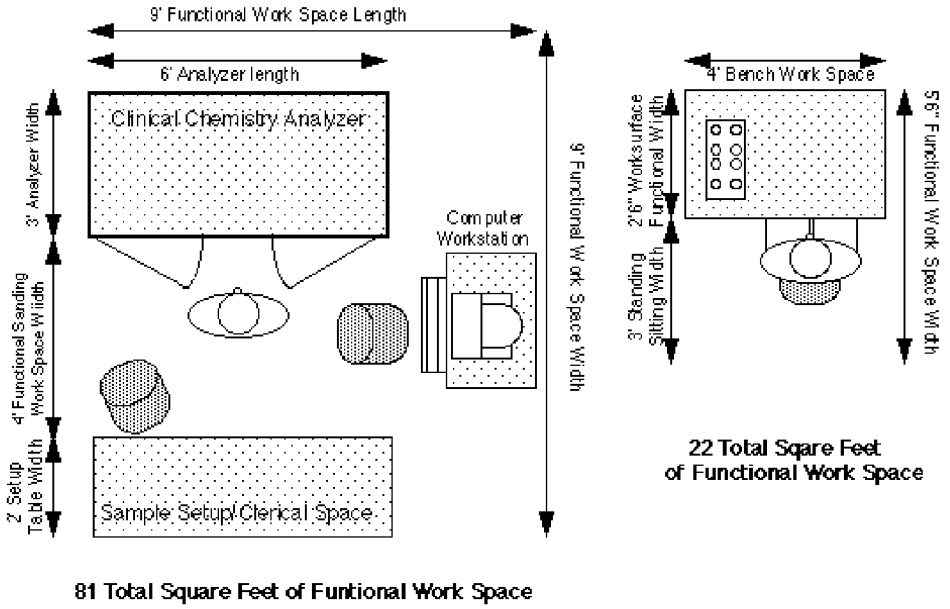

Figure 1. Example of an actual work space for one laboratorian.

size. The quality of a space, or at least its perception by occupants, is also affected by what is put into that space in the way of casework, flooring, walls, ceilings, and windows.

3.3 Control

As noted in Sections 3.1 and 3.2, space is controlled by limiting its quantity and quality; in addition, space is managed by controlling access. Controlling the number of persons using, and traffic patterns to, from, and within a given space directly affects the quantity of space needed and the judged quality of a given space. For example, removing an 8-foot-wide (2.4 m), nonegress or required fire exit, common traffic corridor that runs 100 ft (30.5 m) through the middle of a laboratory returns 800 sq ft (73.6 sq m) of space to the laboratory. Removing the 8-inch-thick (20.3 cm) walls that run down both sides of that same corridor returns another 133 sq ft (12.2 sq m) to the laboratory.

In controlling access to a laboratory, some provision still must be made to receive samples, to allow authorized personnel to move within the laboratory, and to permit visitor access. Also, *there should be some system in place that controls access to the laboratory by unauthorized persons*. Some laboratories process all persons and samples through a front-end "receiving" space. Persons then disperse throughout the laboratory to functional work areas or to supply and support areas as needed. Specimens are moved by staff members, automated track, pneumatic systems, or other automated systems to where they are needed. Intercoms and alarms are needed to inform or alert personnel (e.g., disaster or fire alert, pneumatic tube arrival, or need for assistance elsewhere in the laboratory) and should be planned for in the laboratory design.

3.4 Supply and Removal

Ideally, as space needs increase or decrease, laboratories should be able to expand or contract in size, like a collapsible water jug. In reality, changes in space requirements often necessitate remodeling or reconfiguring existing space to make it more functional and efficient. For example, particular types of cabinetry systems (described in Section 4) are capable of either supplying or removing functional work space, thereby allowing it to be converted to supply or support space. This ability to change existing space so that it is more suitable for new tasks also makes the functional work space safer and more productive.

3.5 Expandability

3.5.1 Planning for Expansion

Because of the rapidity of change and the unpredictability of direction within the fields of science and technology, expanding needs for laboratory space are difficult to predict. Laboratories should be located where there is clear access to an outside wall that abuts "buildable" real estate or, within the facility, next to areas that can be moved to other locations. Too often, laboratories find that they are "building-locked," i.e., surrounded by non-negotiable, institutionally sensitive space. In lieu of other options, sections of the laboratory that must frequently interact with one another may be forced to move long distances apart in order to expand. In some circumstances, modern communication and transport systems, if they are thoughtfully employed, can make such moves less disruptive.

3.5.2 Pneumatic Tube Systems and Computer Networks

Pneumatic tube systems and computer networks provide two means of transporting items and information, respectively, within and between clinical laboratory and hospital complexes. Clinical laboratories commonly employ 4-inch (10.2 cm) pneumatic tube systems to move patient specimens hundreds of yards from collection sites to laboratories and for specimen transport between laboratories at different locations. Larger 6-inch (15.2 cm) pneumatic tube systems are used in hospitals and other facilities to transport pharmacy and miscellaneous items within the complex. Modern pneumatic tube systems have sophisticated computer control and tracking capabilities that allow for expansion as needed.

To enable remote components of a laboratory/ hospital complex to function in an integrated fashion, it is essential to link information-generating components of the laboratory/ hospital complex with locations that require information using a computer network. To this end, high-speed and high-volume information is now transported through copper wire, fiberoptic cable, radio-frequency/ microwave, and other communication systems within and between facilities. Data outlets should be supplied in a manner that allows for adequate supply and flexibility.

3.6 Code and Safety Issues

Laws, codes, regulations, and requirements that pertain to space and access issues in public buildings in general, and laboratories in particular, can be found on consultation with federal, state, and local government agencies, accrediting organizations, and professional societies. The difficulty in assembling and understanding all the pertinent information is such that questions on space and access compliance are best referred to professionals, such as architects, who have access to the most recent information from all required sources.[1] Code compliance can significantly impact laboratory designs. Consequently, code compliance should be addressed by an architect throughout the laboratory design process.

3.7 Fundamentals

3.7.1 The Space Program Statement[2]

One of the most significant documents produced during the laboratory design process is the “space program statement.” It is essential that key personnel that are knowledgeable about the specific operational workings of the laboratory be part of the planning team.

This is referred to repeatedly by administrators, planners, and architects during the planning phase. A well-written program statement justifies space quantities, lists the activities that will be done in each space, and defines the relationships between different spaces. It often is prudent to include a laboratory facilities programming and planning consultant, or an architect who is experienced in the planning and design of laboratory facilities on the planning team during the space programming process.

3.7.2 Proximity Programming

One of the things that must be thought through carefully during the development of a defensible program statement is the functional relationship between each laboratory space. Inappropriate placement of areas that must interact frequently, or that must be covered by a small core staff at the end of the day/shift, can severely compromise an otherwise good laboratory design. If laboratory personnel are required to walk longer distances carrying laboratory samples, the possibility of an accident for both laboratory workers and visi-tors in the area is increased. Proximity diagrams

(Figure 2), bubble diagrams (Figure 3), and block diagrams (Figure 4), may be used either together or separately to consider space relationships.[2]

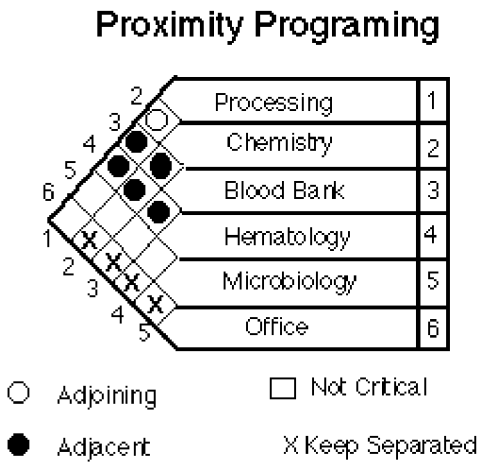

Figure 2. Proximity matrix.

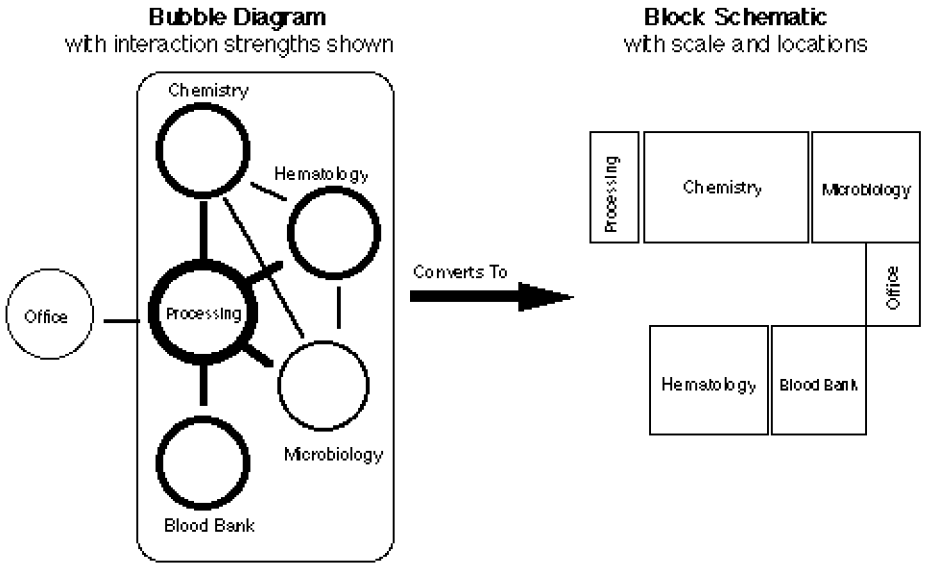

Figure 3. Examples of functional relationship diagrams.

3.7.3 Space Justification

During the creation of the functional relation-ship bubble diagram and a scaled block schematic (Figure 3), a process of space justification and assignment must occur for each area. In the example shown, the bubble diagram shows strengths of relationships and indicates which parts of the laboratory should be close to one another. Assignment of space requires as good an understanding as is possible of current and future space needs. Current space needs can be estimated using a system similar to that shown in Section 3.8 where space is estimated based on existing equipment and instrumentation. Unless work-stations can be consolidated, the expansion of services requires more equipment and thus more space to support the activity. Some of the additional factors that must be considered before final space program figures are assigned are listed in Table 1.

Table 1. Additional Considerations for Allocating Space

1. Utilization	7. Testing workload
2. Number and duties of personnel	8. Regulatory requirements
3. Equipment specifications (size, etc.)	9. Institutional standards
4. Building systems (mechanical/electrical/ plumbing)	10. Built-in "flexibility"
5. Psychological perceptions of space	11. Position and status
6. Capital costs/budget limitations	12. Circulation clearances

In considering all of these factors, those involved in the development of the space criteria must exercise careful judgment. The subsequent phases of the planning and design process will provide the opportunity to further test and confirm net square feet (NSF) and gross square feet (GSF) area allocations. Judg-ment and experience factors are also based on specific space standards for different functions and activities. For example, a conference room space factor may vary between 15 NSF (1.38 net square meters) (low range) to 25 to 30 NSF (2.3 to 2.8 net square meters) or more (high range) per person. The function of the conference room, e.g., a board room versus a department conference room, will also deter-mine its square footage per person. For example, an institution's "Board of Trustees Conference Room" will have a totally different "space factor" than a department conference room.

3.7.4 Net vs. Gross Square Feet

Actual functional work space available in a laboratory, i.e., the net usable square footage of a space, may be 35 to 55% less than the gross square footage allocated. This "net usable" space is a function of the efficiency of a laboratory design. The additional square feet are those necessary to accommodate partitions; corridors; vertical transport; circulation; and mechanical, electrical, plumbing, and structural elements within the laboratory. Consequently, an area's gross square footage should be divided by 1.35 (74% efficiency) to 1.55 (64% efficiency) to estimate the net usable square feet.

3.7.5 Equipment Listing

An essential part of the Space Program Statement is a list of all of the equipment within each laboratory area. This list should give the length, width and height, as well as voltage and amperage requirements for every piece of equipment. Developing a notebook of equipment manufacturer specifications for dimensions, clearance, power, access, temperatures, gases, plumbing, weight and emergency requirements can save time should they need to be referred to later. The length and width are used to calculate the needed space in square feet, as shown in Section 3.8. The manufacturer's recommended space requirement for the instrument may exceed the actual measured size, and should therefore be used in calculating the needed space. Access to the rear or side of the instrument for maintenance and repair may also be a manufacturer's recommendation, and should be considered when calculating the needed space (e.g., open counter space on the side or rear of the instrument). The voltage and amperage requirements are used to calculate power requirements (e.g., dedicated lines to provide uninterrupted power to major instruments) and heat generation of the

equipment for estimation of ventilation and cooling needs. Once this list is assembled, a space and function programming summary can be developed (using the information from Figure 2) similar to that shown in Table 2.

From Koenig AS. *Medical Laboratory Planning and Design*. Chicago: College of American Pathologists, 1989. Reprinted with permission.

Table 2. Space and Function Programming Summary

Area	Space Name	Square Feet (Square Meters)	Adjoining	Adjacent	Keep Separated
1	Processing	150 (13.8)	2	3, 4, 5	
2	Chemistry	400 (36.8)	1	3, 4, 5	6
3	Blood Bank	300 (27.6)		1, 2, 4, 5	6
4	Hematology	350 (32.2)		1, 2, 3, 5	6
5	Microbiology	300 (27.6)		1, 2, 3, 4	6
6	Administrative Office	100 (9.2)			

Submitted by:_____ Date:_____

3.7.6 Laboratory Layout and Working Drawings

Designing the actual layout of a laboratory is a very individual process. Each laboratory is unique in the tests that are performed, the amount and expertise of personnel, the instrumentation, and the general organization of work processes. To create a set template for use in all laboratories is not a practical or efficient solution.

There are several steps that should be incorporated into the beginning of a laboratory design that will direct the layout to work best for the individual lab. Codes and flexibility are two additional issues that should be discussed and accounted for in the preliminary layout. Typical constraints that are encountered are a limited amount of available space, and financial limitations.

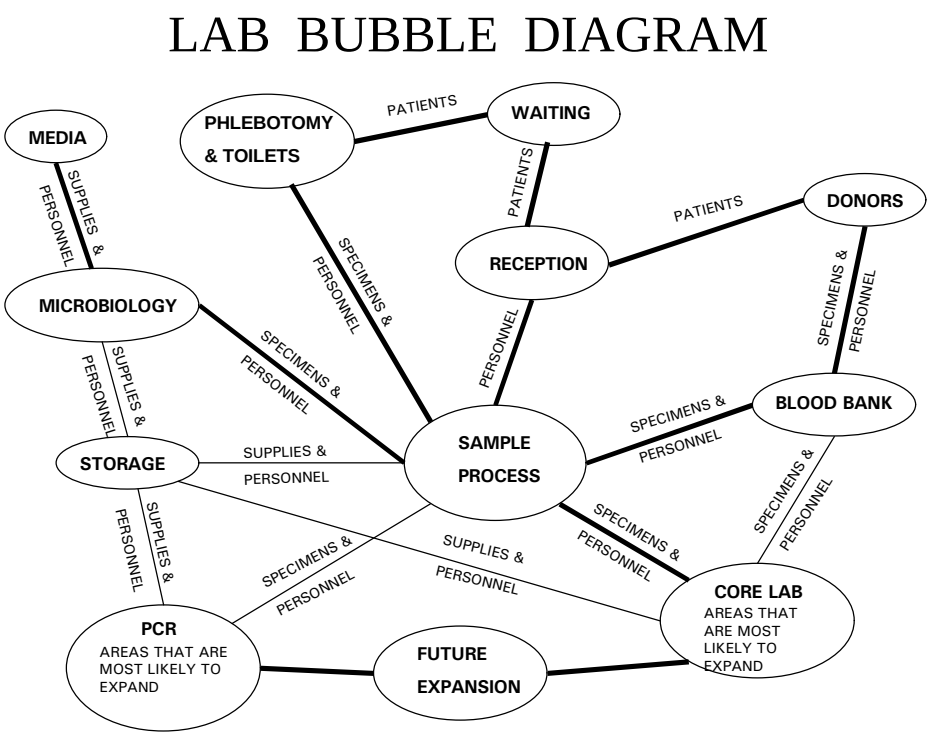

Figure 4

3.7.6.1 Movement

Evaluating the movement of personnel, patients and specimens is the first step in the layout of a laboratory area. For the departmental layouts, a bubble diagram showing the relationships between the different departments will initially suggest the most efficient solution. The solution should be based on the relative movement of all three factors, as illustrated in Figure 4. Using heavier lines to highlight the most important relationships is useful in determining the actual floor plan.

The same analysis of movement can be used on a smaller scale to determine the layout of doors, casework, and equipment in each specific area of the lab. In this scale the specimen flow is the most important. (See Figure 5.) The amount of equipment, furniture, personnel, supplies and circulation is addressed at this scale and can significantly alter the actual square footage requirements.

SPECIMEN MOVEMENT

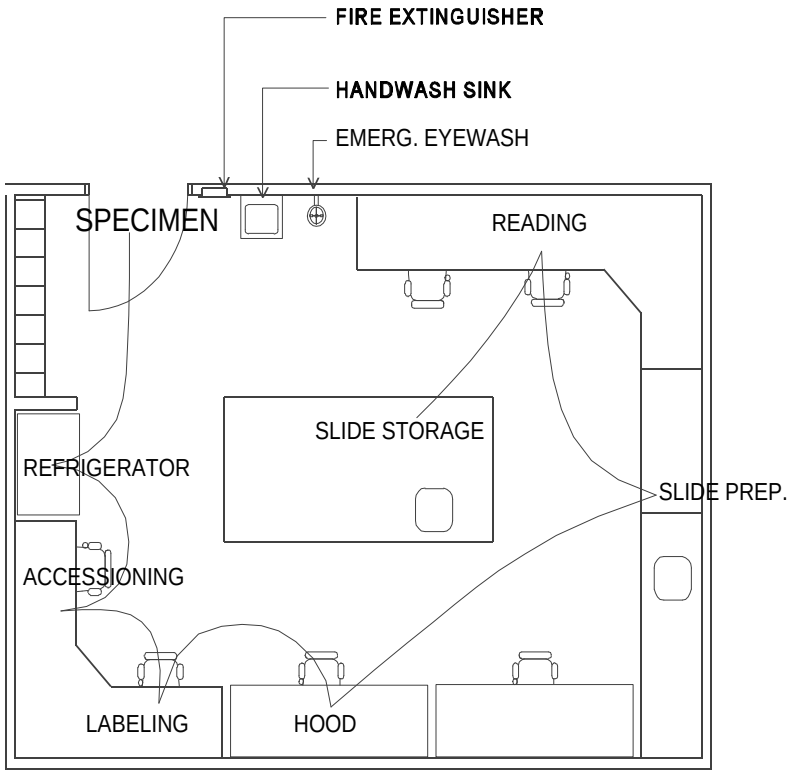

Figure 5

3.7.6.2 Flexibility

When determining the layout of the laboratory it is important to prepare your design to adapt to future changes. The amount of flexibility incorporated into the design is dependent on the amount of change you anticipate and the type of testing you do. In a laboratory that is predominantly automated, the possibility of equipment changes is very high. Utilization of flexible casework would facilitate the instal-lation of a robotic system at minimal in-convenience and cost. Areas that do mainly manual methods may not experience as much reshuffling. However, it would be prudent to realize that methods that have long been manual are now becoming automated.

FLEXIBILITY

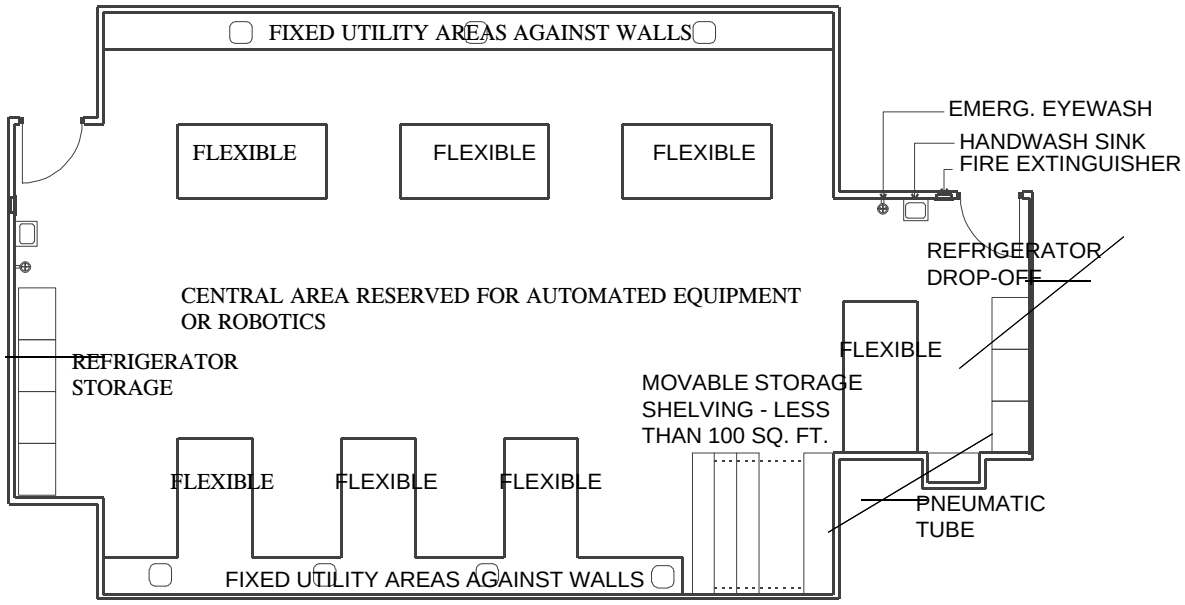

Figure 6

Flexibility in the layout is accomplished through the use of flexible casework, establishing areas that are predominantly utilities and ensuring that all your utilities can meet the changing needs of your people and equipment (see Figure 6).

Mechanically, the inclusion of flexibility is addressed through the type and capacity of your air handling system and the accessibility of plumbing and duct work for easy maintenance and rapid reconfigurations.

Electric and communication wiring should be sufficient for your present needs as well as allowing extra capacity and accessibility to allow equipment to be added and moved. You should not be constrained on the area that you use a particular instrument because of the location of relevant outlets. The profusion of computers and printers in the laboratory requires that you are able to add and move them with ease.

Incorporating organized wiring through the use of wire mold and cable trays can ease the disruption that accompanies change.

SAFETY MODULE

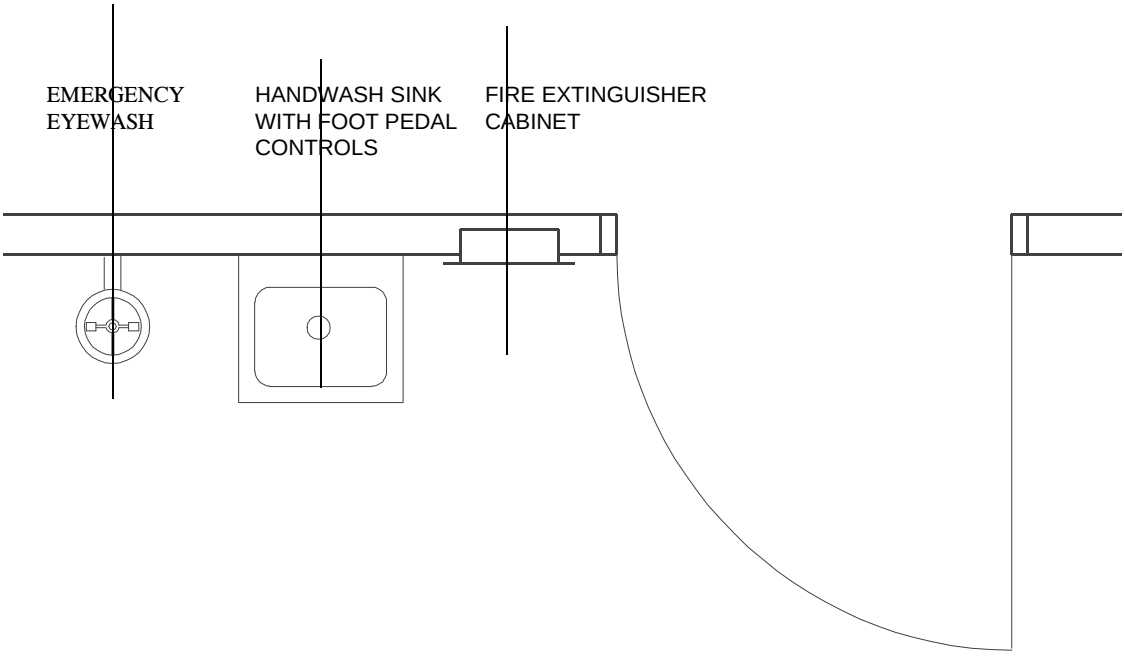

Figure 7

3.7.6.3 Safety

The size and layout of the laboratory is affected by life safety, and building codes that have minimum requirements for clearances and emergency escape routes. Utilities that ensure the safety of personnel and patients should be itemized in the initial layout. Not all safety equipment is required in all labs and each must be evaluated individually.

Handwash sinks[a] are required in most laboratories and are best situated near an exit as a reminder to personnel that they must wash their hands before leaving the laboratory. These sinks are not to be used for specimens and procedures so it is best to have them isolated as a separate unit. Handwash sinks are required in all laboratories and any area that has direct patient contact.

Emergency eyewashes and showers are required within 100 feet of where hazardous chemicals are used. The intensity of the hazard should be weighed and used to determine if the equipment should be located closer.

Setting up a safety module (handwash sink, emergency shower, emergency eyewash, fire equipment, as needed) that can work in each laboratory area allows for ease of layout and makes it easier for personnel to find this equipment in the case of an emergency (see Figure 7).

[a] Referred to as lavatories in standards of the U.S. Occupational Safety and Health Administration (OSHA)

ADA CLEARANCES

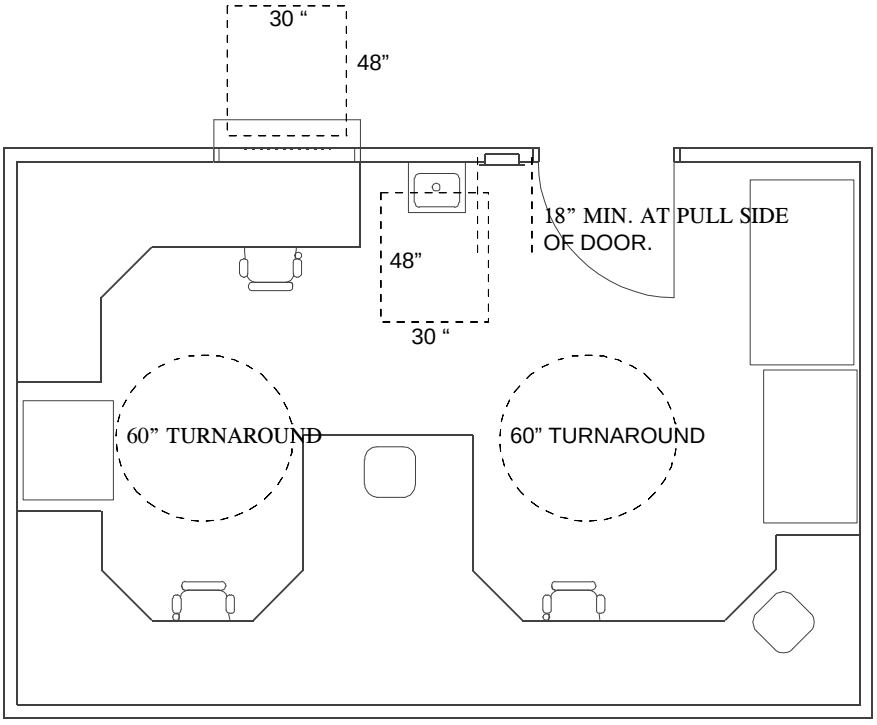

Figure 8

3.7.6.4 Disabled Employee Considerations

The layout should adhere to regulations regarding those who are physically challenged.[b] It may be required that all public and common-use areas of new medical care facilities as well as alterations to existing facilities be accessible. Any area that would be used by outpatients or visitors may be included. In the laboratory setting this could include waiting, phlebotomy, toilet and donor areas.

Areas that are designated as employee-only work areas should be designed to allow an individual with disabilities to approach, enter, and exit. In the event that an employee is handicapped the laboratory should be revised to meet this employees needs. Adapting a laboratory for an employee with disabilities after it is constructed can be costly and disruptive. Incorporating allowances for the handicapped in the initial layout not only saves later changes but it allows more room for everyone working in the laboratory (for an example see Figure 8, *Clearances Specified by the ADA*). The addition of casework that can be adjusted in height can allow a laboratory to adapt to a disabled employee and to the variety of nondisabled employees with ease.

3.7.6.5 Spacing Guidelines

There is no easy method to determine the square footage requirements for all laboratories. The necessary space for a particular laboratory requires an understanding of all the functions. Factors such as equipment, methodologies and personnel will greatly effect the final size.

[b] For example, the *U.S. Americans with Disabilities Act (ADA).*

LAB CLEARANCE

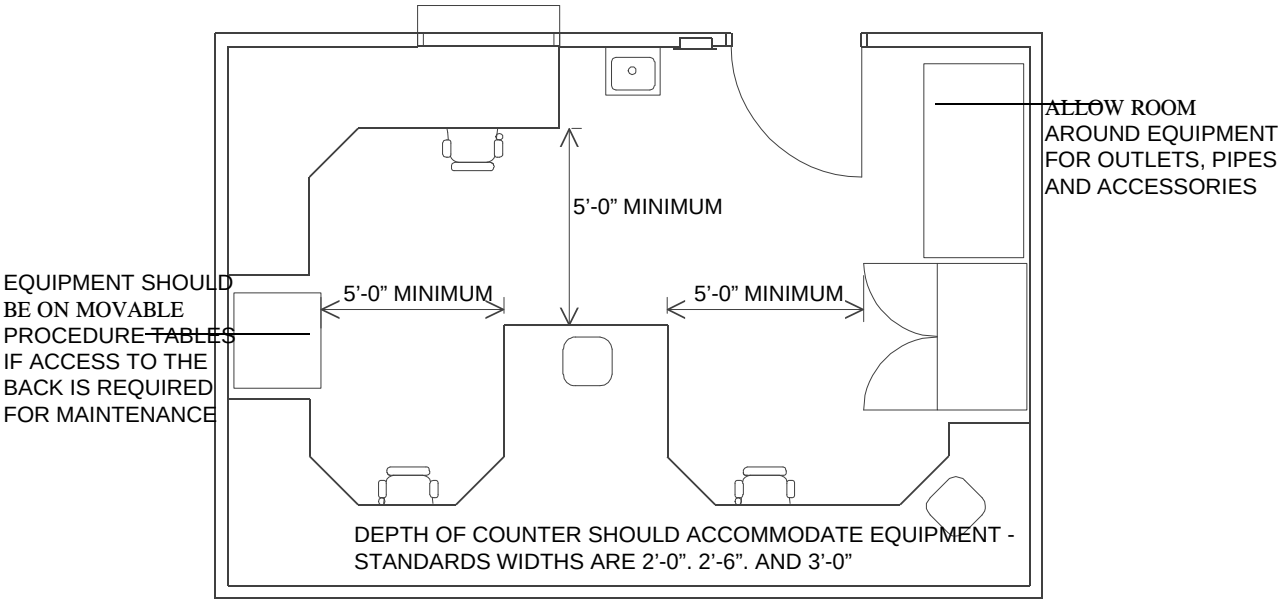

Figure 9

Space must be allowed for ease of maneuvering throughout the laboratory. This includes the area between casework, in aisles and around equipment (see Figure 9). The areas set aside for circulation should be comfortable but not so large as to compromise the efficiency of the laboratory.

Allowing space around equipment is necessary for proper ventilation and ease of maintenance. Often equipment manufacturers will note distances from walls that are required for particular pieces. Ease of maintenance is achieved by allowing space behind instruments to allow personnel to reach utilities and controls. This can be achieved by leaving an aisle behind large instruments or placing equipment on procedure tables with lockable casters that can be wheeled out to expose the backs.

3.7.6.6 Fume Hoods and Biosafety Cabinets

Hoods of any type should be located as far from doors as possible. This follows the guideline that hazardous procedures should be performed away from primary egress routes. In addition to protecting employees and patients, the judicious location of movement paths can minimize disruptive air movement that can jeopardize the effective operation of the hood itself.

3.7.6.7 Biosafety Level 3 and Requirements

When designing a laboratory, the biosafety level of the activities must be considered according to the criteria outlined in Appendix B. Most clinical laboratory testing areas would be considered level 2 while the receiving areas would be considered level 1; neither of which

BIOSAFETY LEVEL 3 PLAN

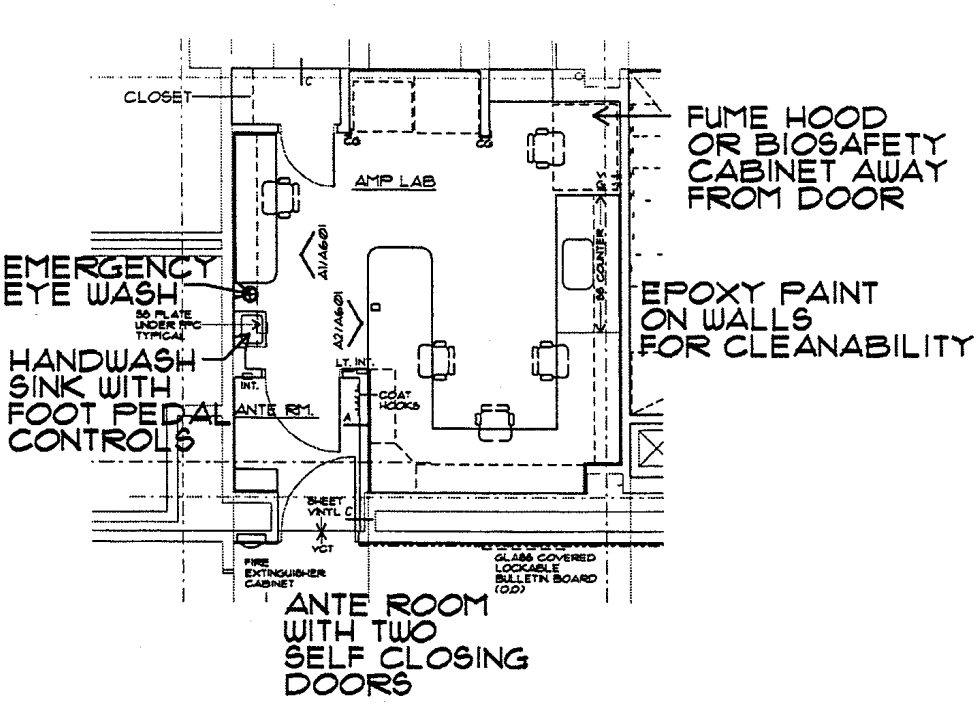

Figure 10

requires the special design considerations of level 3 and 4 Biohazards.

Level 3 is defined as areas where work is done with indigenous or exotic agents that can cause lethal or serious disease through inhalation. Because of the potential hazards of these agents there are layout criteria for laboratories handling them.

This area must be separated from traffic areas in the building by two sets of self-closing doors. This design is very much like anterooms that are found before isolation areas. The hand-wash sink must be located next to the door and it must have foot pedal controls. Eyewashes are required in each of these areas (see Figure 10).

Biosafety level 4 is necessary when the agents pose a high risk for life threatening disease through aerosols. The layout requirements are more stringent than for level 3.

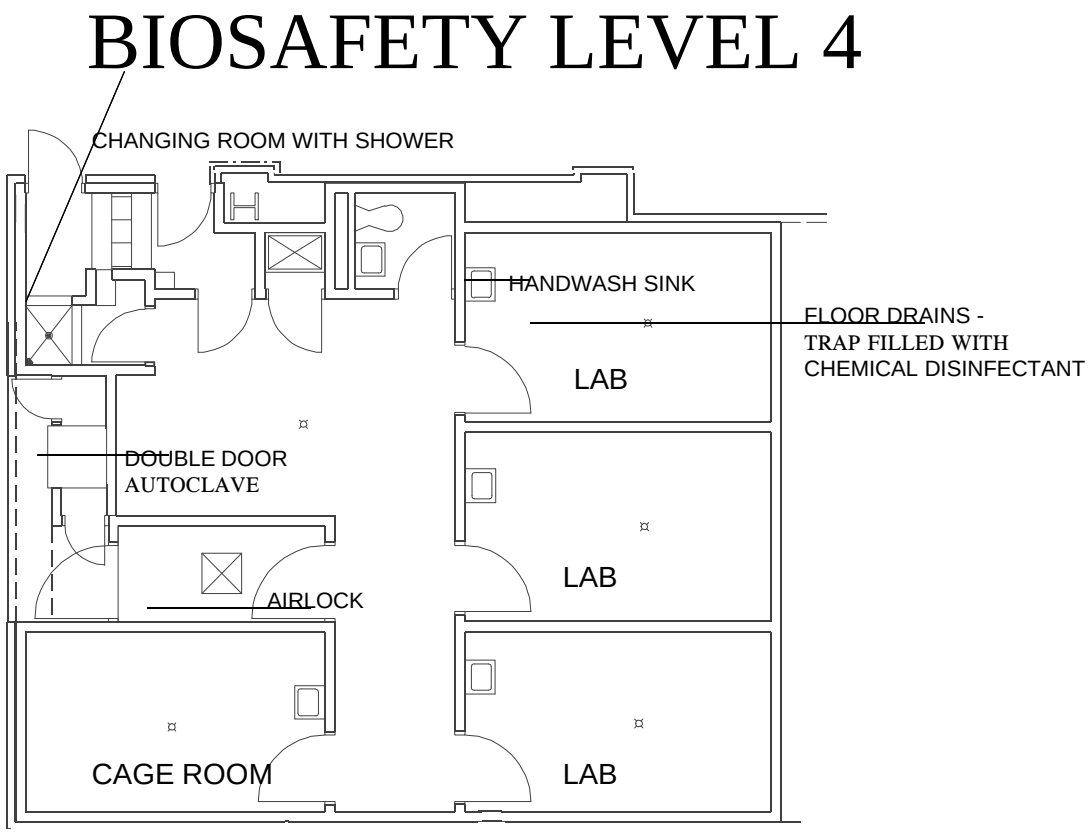

Figure 11

The laboratory must be in a separate building or isolated zone. Changing rooms separated by a shower have to be provided. This may include a pressure suit area with a chemical shower. Materials that pass into and out of the laboratory must go through an airlock, fumigation chamber, or double door autoclave (see Figure 11).

3.7.7 Staff Space

Staff members are a significant component of any laboratory; therefore, planning for how they will move and work within the laboratory should be done early.[3-6] Note that while everyone takes up space, some staff members need more space than others to function and move safely. Special consideration should be given to persons with disabilities. The design criteria should be in compliance with employee disability requirements. The physical norms of men and women while standing, suggest that typically, men (18" [45.7 cm] W x 12") [30.5 cm] D occupy about 1.5 sq ft (0.14 sq m), while women occupy about 1.3 sq ft (0.12 sq m) (15.5") [39.4 cm] W x 12" [30.5 cm] D) as shown in Figure 12.[c]

[c] Note that the space requirement for someone in a wheelchair is different than the space requirement of 1.3/1.5 sq ft (0.12/0.14 sq m).[6]

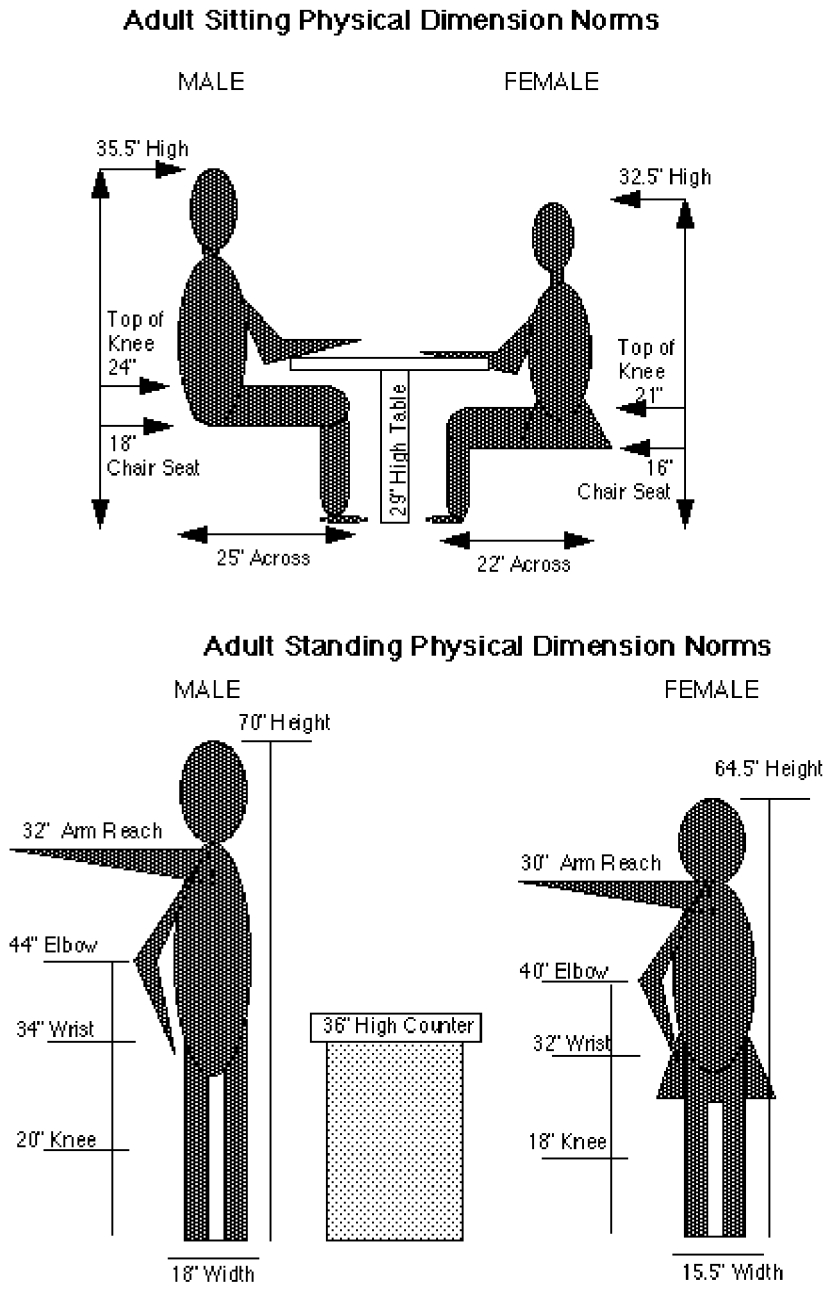

Figure 12. Physical norms for adult men and women in the United States. (To convert inches to centimeters, multiply by 2.54.)

This 0.2-sq ft difference means that 6.0 men would occupy the space that it would take 6.9 women to occupy, which makes the difference in standing space insignificant. Depending on the style of the chair and individual sitting habits, while sitting at a bench, the chairs of

both men and women extend from 12 to 24 inches (30.5 to 61 cm) into the aisle. With typical chairs about 20 inches (50.8 cm) wide, the same 6.0 men who occupied 9 sq ft (0.83 sq m) while standing occupy between 10 and 20 sq ft (0.92 and 1.8 sq m) while sitting, or an average of 2.5 sq ft (0.23 sq m) each. As a matter of practicality, laboratories should always be designed so that individuals of different physical size can work in them safely and effectively.

3.8 Calculations

3.8.1 Current Space Needs Calculation[7]

One of the most easily defended methods of determining space needs is to determine how much space a laboratory should have based on what is currently done within that laboratory.

The total net space required (TNS) is estimated by making and totaling a series of measurements in the laboratory. The bench work space (BWS) is estimated by simply measuring the linear footage of all analysis equipment (AE) and clear working space (CWS) on the benches, and then multiplying it by the sum of counter depth (CD) plus desired aisle width (IW). To the BWS, add the actual square footage of floor-mounted items (FMI), such as refrigerators, printers, and workstation areas (e.g., chemistry profiler and "U"-shaped work area), while allowing for necessary clearances.

Example:[7]

$BWS = [(AE + CWS) \cdot (CD + IW)]$
$= [(60 \text{ ft } (18.3 \text{ m}) + 20 \text{ ft } (6.1 \text{ m})) \cdot (2 \text{ ft } (0.61 \text{ m}) + 3 \text{ ft } (0.91 \text{ m}))]$
$= 400 \text{ sq ft } (37 \text{ sq m})$
and where

$FMI = 180 \text{ sq ft } (16.6 \text{ sq m})$

$TNS = BWS + FMI$
$= 400 \text{ sq ft } (37 \text{ sq m}) + 180 \text{ sq ft } (16.6 \text{ sq m})$
$= 580 \text{ sq ft. } (53.6 \text{ sq m}).$

With the 3-foot (0.91 m) aisle used in the calculation, it is assumed that there is an opposing counter so that the actual aisle is 6 ft (1.8 m) wide, otherwise the IW should be at least 4 ft (1.2 m) wide. If a functional area is planned in which the laboratory personnel have no experience, the experience of others should be tapped, and visits to laboratories should be planned to get ideas on which to base BWS and FMI estimates. Some space estimates may have to be calculated based on the experience of consultants or others already engaged in the activity.

3.8.2 Future Space Needs Calculation

The specific equipment information assembled during preparation of the program statement and the current space needs assessment serve as the foundation for predicting future space needs. Rather than relying on data generated from other locations with possibly different needs and working environments, a customized space needs prediction can be made based on changes in total equipment/instrumentation size and benchtop workspace. Workload changes are often not reliable predictors of space needs because a rise in workload could permit the acquisition of automated equipment, which could reduce the space needs of less-automated workstations and actually free laboratory space. Each new generation of laboratory equipment has more functionality than its predecessor. However, what does generate the need for additional laboratory space is the initiation of new laboratory services, each of which will carry its own burden of equipment, workbench, personnel, refrigerator/freezer, and ambient storage needs. Review, oversight, and clerical functions are increasingly taking up more time and space in laboratories. Thus, calculating the total square footage requirements of new services and/or other space-consuming requirements facilitates a reasonable and defensible prediction of future space needs.

3.9 Minimum and Recommended Criteria

Table 3 shows the minimum and recommended criteria for a laboratory.

Table 3. Criteria for a Laboratory Space

	Recommended	
Aisle width between casework	5-6'	(1.5 - 1.8 m)
Aisle width between casework and wall	4-5'	(1.2 -1.5 m)
Countertop depth	30"	(76 cm)

4 Casework/Millwork/Furnishings

Casework, millwork, and other furnishings are among the most dominant visual features of any laboratory. Casework is typically a pre-designed, pre-engineered and manufactured cabinet type. It is generally constructed to "industry standards" based on modular units. It can be ordered and purchased directly from various manufacturers' stock catalog listings. Some casework units are made from wood, metal, and composition materials or combi-nations of such materials. Casework is usually considered and installed to appear as a built-in building item. Casework can also be removed, relocated, and reused in other areas of a building. The laboratory staff should be consulted throughout the process of casework selection.

Contrary to casework, millwork includes cabinet items, with associated trim, that have been specifically "custom designed" and manufactured for a particular location. Wood, composition materials, or a combination of such materials are generally used to construct millwork. Millwork is designed and detailed, and it is included on the construction documents (working drawings and specifications). Because of its "custom design," millwork, can almost never be "reused" in other locations. Casework is normally given performance criteria in the specifications, and possible stock numbers if only one manufacturer is being considered. Millwork, however, is detailed to tell the contractor specific construction criteria since it, unlike casework, is often built for the customer.

The design and layout of furnishings define traffic patterns, work flow and, to a great extent, the functionality of a laboratory. Laboratory safety is also directly affected by decisions made about the quantity, quality, type, and organization of laboratory casework and furnishings. Consequently, those working in laboratories should be able to give informed input as to how they use laboratory casework and furnishings. They should also be able to discuss elements of laboratory design and layout that they know from experience do not work. Discussions with actual users of the casework being contemplated is invaluable in deciding on the actual utility of the options under considerations.

Laboratory casework design has evolved over the past 40 years to keep pace with the changing needs of different types of laboratories. The large selection of different styles of high-quality laboratory casework now available provides a greater opportunity for satisfaction than ever before. However, remember that any selection of laboratory furniture should focus on optimal satisfaction of the "form, fit, and function" issues specific to that type of laboratory. To achieve a laboratory that is both functional and safe, this section focuses on some issues that should be remembered when selecting casework and furnishings.

4.1 Quantity

A laboratory should have enough well-configured casework, both floor and overhead if necessary, so that the functionality and safety of the laboratory is not compromised. As indicated in Section 3, too much casework for the square footage of laboratory space available is a more common problem than too little casework. This situation exists because casework can be acquired and placed in a laboratory relatively quickly with few levels of approval necessary. However, because of the lengthy approval processes required, acquiring more space for a laboratory (which could be what is actually needed) is a slower process.

An excess of casework and furnishings can reduce the space available for personnel to a point where productivity and safety are compromised. For example, in an open laboratory where there are few fixed walls, overhead storage may be attached to the same free-standing support/service chase systems that support floor casework. Some open laboratories may begin with little overhead storage and add the storage later as needed.

One of the main functions of casework is to store things conveniently until they are needed. As noted in the more complete discussion of storage in Section 5, laboratory casework often becomes overwhelming, dysfunctional, and unsafe because more items are put into the storage space than are taken out.

The planner should consider the impact of locating fixed utilities (e.g., gas, vacuum, air outlets) on counter surfaces. Locating these utility chases and reagents shelves frees the

work surface for other functions and improves flexibility.

4.2 Quality

Discussions of the quality of laboratory furniture by laboratory staff members generally focus on "fit and function" issues (see Table 4). Consequently, drawers that do not work properly when loaded, countertops that sag over time, and casework that is defaced and becomes dysfunctional after routine use is judged to be of inferior quality no matter how much each cost. Therefore, while appearance is an important consideration, fit and function issues increasingly dominate the perception of the quality of laboratory furniture. The planner should consider warranties, trade-in policies, obsolescence, scope of inclusive accessories (task lighting, etc), and actual field performance when selecting product. Laboratory staff should always be involved in the development of the specifications for casework and equipment.

Table 4. Fit and Function Issues of Laboratory Furniture

- Durability and suitability of benchtops and interior and exterior casework construction to chemicals, staining, biological contaminants, and normal "wear and tear" caused by moveable furniture, such as chairs and carts.
- Ruggedness of drawers and the construction of their support system, as well as how smoothly they operate throughout their range of movement when fully loaded.
- Effort involved and satisfaction with the end result when modular or flexible furniture system components are rearranged.
- Stability of benchtops, shelving, and overhead casework when loaded to capacity.
- Ease of repair should a drawer, cabinet door, casement side, or benchtop become damaged.

4.3 Control

Because authorization may be necessary before funds can be spent, control processes should be among the considerations for acquiring and maintaining laboratory furniture. Most facilities have a review and approval process in place to help avoid mistakes in form, fit, and function.

4.4 Supply and Removal

Getting furniture physically into and out of a laboratory is not a problem as long as the width of the casework is smaller than the width of the door openings. Main laboratory doors should be at least 4 ft (1.2 m) wide. Interior doors may be only 3 ft (0.91 m) wide, which makes the placement of some furniture and equipment impractical, or at least difficult within a laboratory.

Modular and flexible furniture systems are designed to have moveable casework units. Electrical wiring is routed through the back steel supporting chase systems; thus, it is generally unaffected when sections of case-work are moved. If all flooring is laid before any casework is placed, finished and generally homogeneous flooring exists beneath casement components should it become necessary to completely remove these components to allow the placement of a large, floor-mounted instru-ment, for example.

4.5 Expandability/Flexibility

The addition of laboratory furniture depends on the availability of space, components, and funds. Some furniture styles are only available for a few years, which can create future compatibility problems.

Because what is done within any given laboratory space may change as often as every 6 to 12 months, the terms "flexibility" and "expandability" are often used interchangeably to describe a requirement of the modern laboratory. Any change in the purpose of the laboratory space increasingly requires, or at least suggests that the laboratory space may need to be reconfigured. Furnishings now exist that offer such flexibility: They allow for the removal and addition of components when necessary. In general, most types of furnishings can be changed with relative ease. Where these furnishings differ is in the difficulty of adapting the electrical and plumbing support utilities to the new configuration.

4.6 Code and Safety Issues

Casework should be designed to accommodate those that are physically challenged and consideration should be given to Section 6.6 of this document.

Special care should be taken to ensure that existing casework systems can support proposed loads and uses.

4.7 Fundamentals

Laboratory furniture is routinely used by and therefore must be designed for more than one user. All users of a particular work area must be able to function comfortably and safely, regardless of their physical size. Tables and chairs that cause the laboratory worker to sit at an awkward angle because he or she is too large are more than an inconvenience. They are, in fact, a health and safety hazard. Fortun-ately, high quality adjustable seating and case-work are available that can significantly reduce health and safety hazards as well as increase comfort and convenience for the user.

As shown in Figure 12, physical norms for adult men and women in the United States require typical desks and stand-up work benches to be 30 and 36 inches (76.2 and 91.4 cm) from the floor, respectively. In cases where most persons are significantly shorter than the U.S. norm (e.g. in some Asiatic countries), adjust-able seating allows furniture height to be adjusted accordingly. Flexible casework sys-tems are also useful when it is necessary to raise or lower the height of casework. The height of the work counter should be based on the type of equipment to be placed on the counter, as well as access to the equipment.

4.7.1 Types of Casework Systems

The two types of casework systems available today are fixed and modular. The performance characteristics attainable with each type are similar. The primary difference between the two relates to flexibility. Fixed casework has a long history of success where the purpose and activities of the laboratory remain stable. Indeed, the primary advantage to modular furniture is that comparatively, it is easily reconfigured or moved when necessary. Casework should be selected only after it is seen and examined first-hand for fit, finish, and functionality.

4.7.1.1 Fixed Casework

With the availability of contemporary styles and its functionality, fixed casework continues to be the furniture of choice for many modern laboratories. Fixed casework in steel, wood, or of plastic laminate construction is available in the widest selection of styles, colors, surfaces, and configurations. Wooden and to an even greater extent, plastic laminate fixed casework, lends itself to cost-effective custom construc-tion. if necessary. In the past, one of the main objections to fixed casework was that, when a section was removed, exposed pipes and concrete were often visible. This is because the casework components were not installed with removal and rearrangement in mind. Some fixed casework lines available today provide increased flexibility without sacrificing features. This is accomplished by installing casework after all finish flooring is laid and by using utility chase systems behind the furniture that are similar to the systems employed with modular casework.

4.7.1.2 Modular Casework

If the needs of a laboratory dictate that modular casework should be used, the issues to consider when choosing a particular system include the flexibility, strength, and durability of each. Modular casework systems differ substantially in how easily workstation height, drawers, and overhead storage areas can be reconfigured. Other points that distinguish modular systems are load-bearing capability, finish options, and durability. Most modular systems attach the countertops, drawers, and storage cabinets to a support system attached to a wall or a steel support framework. In turn, this framework is attached to a wall or tubular steel support structure. When selecting a system, it is important to understand exactly how the modular units attach to the support structure, then assess the strengths and weaknesses of each system relative to laboratory design objectives. Since some modular systems may include wiring and electrical connections as part of the price, it is important to know what you are getting so that offerings can be compared fairly.

4.7.1.3 Mobile Casework and Furniture

Mobile casework and furniture with swivel-type wheels are useful alternatives for supporting heavy, desk-top equipment for which occa-sional access to all sides is necessary. Mobile casework and furniture are also useful if

additional work surfaces and/or supply storage space is needed next to a workstation.

4.7.1.4 Combination Casework

Combination casework is useful if it becomes necessary to change part of the laboratory on relatively short notice (for example, in the case of a laboratory that does contract work that changes every few months). Each laboratory area can be composed of a combination of fixed casework, modular casework, and mobile furniture (e.g., in proportions of 60, 30, and 10%, respectively).

4.7.2 Computer Workstations

As the functionality of the single computer workstation increases, laboratorians are spending more total time and more time without getting up to perform other tasks at their computer workstations. Computers simply give laboratorians fewer reasons to move about to obtain and process information and even to interact with others. Consequently, as the use of computers increases, so does the thought given to the design of a typical computer workstation.

4.7.2.1 Video Display Terminal (VDT) Screens and Keyboards

Because small differences in fit and function may cause big differences in the susceptibility of personnel to fatigue and injury, more adjustability is probably designed into the typical computer workstation than into any other type of furnishing within the laboratory. For example, the ability to properly adjust the VDT screen and keyboard to comfortably accommodate each person is especially important. Keyboards can be added to existent casework by adding a keyboard drawer underneath a 30-inch (76.2 cm) high, sit-down work area. If the distance from the bottom of the keyboard drawer to the floor is less than 25 inches (63.5 cm), persons over 6 ft (1.8 m) tall typically will not have adequate knee clearance. To achieve the proper wrist angle relative to the keyboard, the chair height or keyboard height, or preferably both, should be adjust-able.[8,9] Workstations designed especially for computer work should, minimally, allow the height and angle of the VDT and the keyboard drawer to be adjusted. Some systems allow the height of the entire work surface to be altered. If neck, back, and eye strain are to be minimized, the VDT screen should be adjustable so that each person may position it for the most comfortable height and angle of view. Light reflection off the screen is a prime source of eye strain; methods to minimize such reflection are discussed in Section 7. The video display terminals (computer monitors) and keyboards may be mounted on adjustable arms which permit individualized placement of the monitors and uncluttering of work surfaces.

4.7.2.2 Chairs

Within some laboratory environments, laboratorians may perform their duties while sitting in chairs for 50 to 75% of their working day. Because laboratorians using computer workstations move less from their chairs than while performing most other functions, nowhere is the importance of seating greater than in this area. Chairs used for computer workstations should have exceptionally good seat padding and back support. The abilities to easily raise and lower the chair height, as well as swivel and adjust the back support, are critical to chairs used at computer work stations.

4.7.3 Electrical

Laboratories should plan for supplying various types of electrical power and for future expansion. Power in modern laboratories include dedicated circuits, uninterrupted power supplies (UPS), power stabilizers to supply clean power to equipment, and emergency power of differ-ent voltage and phases. Equipment speci-fications should be checked for requirements when determining power needs.

4.7.4 Countertops

Countertops are available in a wide range of materials and colors (Table 5). The type of surface material selected should depend on the type of laboratory work to be done. Unique requirements for countertop surfaces can exist within each laboratory area that may not be applied to all areas (greatly reducing cost). The factors that determine the best choice of surface material include load-bearing properties and resistance to heat, acid/alkali, organic sol-vents, staining, and impact. The most reliable way to determine if a proposed surface material is suitable is to get a 2- x 3-foot (0.6- x 0.9- m) section from the supplier and subject it to overnight exposure to the most aggressive staining materials, acids, alkalis, and solvents that it will likely encounter. Then determine the difficulty in cleaning and the degree of permanent damage to the surface. Another

consideration is the potential for microbiological growth with particular countertop configurations which must be evaluated for the laboratory application involved.

Table 5. Countertop Materials

Wood or Wood Core	Natural or Synthetic Stone	Metal
Maple	Slate or granite	Stainless steel
Plastic laminate	Cast resin	
	Portland cement	

Corner edges of countertops rate just behind the surface in the importance of their resistance to damage as a result of exposure to potentially damaging substances or events. Experience shows that rounding countertop corners and using shock-absorbent banding greatly reduce the likelihood that something striking a corner or lateral edge will cause damage to the case-work or injury to personnel. Such rounding and banding is especially useful with plastic laminate over wood particle core construction casework. The length of countertop sections is an important consideration in areas that may undergo changes in the configuration of the casework or where the countertop may, periodically, be removed altogether. A continuous, 12-foot-long (3.7-m-long) countertop may, for example, look good and seem efficient until it becomes necessary to remove two 4-foot (1.2-m) sections of casework to create an 8-foot (7.3-m) bay for a floor model analyzer. The creation of such a bay would require that the continuous length of the countertop be cut and patched.

4.8 Calculations and Specifications

The formulae in Table 6 can be used to convert square inches to square feet of floor space and to convert cubic inches to cubic feet of storage space; also following are some specifications for general computer workstations.

Employing these formulae in the planning of a laboratory would show that replacing a 36-inch (91.4 cm) high stand-up workbench with a 30-inch (76.2 cm) high, sit-down workbench (with the same length and width) reduces the available storage space from 36 to 30 cu ft (7.6 to 4.4 cu m). This is a difference of 16.7%.

Table 6. Formula Used for Converting Measurements

From	To	Formula
Sq in	sq ft	$\frac{L\ (\text{in}) \cdot W\ (\text{in})}{144}$
Cu in	cu ft	$\frac{L\ (\text{in}) \cdot W\ (\text{in}) \cdot H\ (\text{in})}{1{,}728}$
Sq cm	cq m	$\frac{L\ (\text{cm}) \cdot W\ (\text{cm})}{1 \times 10^4}$
Cu cm	cu m	$\frac{L\ (\text{cm}) \cdot W\ (\text{cm}) \cdot H\ (\text{cm})}{1 \times 10^6}$

Following are some specifications for general workstations:

- The heights of the sit-down workbench and desk are generally 30 inches (76.2 cm).
- The height of the stand-up workbench is generally 36 inches (91.4 cm).
- The computer keyboard height is generally 26 to 27 inches. Persons over 6 ft tall may need greater floor-to-keyboard clearance, which is sometimes achieved by removing the keyboard drawer underneath the work-station (knee access beneath the casework should be 28 to 29 inches; 71.1 to 73.7 cm).
- Workbench and desk depth (front to back) are generally 30 inches (76.2 cm). This is because 36 inches (91.4 cm) can be difficult for some persons to reach across to gain access to overhead storage, and 24 inches (61.0 cm) is not wide enough to accommodate the equipment.

4.9 Minimum and Recommended Criteria

Table 7 shows minimum and recommended criteria for laboratory casework and furnishings.

Table 7. Criteria for Laboratory Casework and Furnishings

	Minimum	Recommended
Multiples of cu ft work-generating area to storage needs	2	2.5
Chair swivel (S), height (H), and back (B) adjusts	SH	SHB
Chair vertical adjustment range	5" (12.7 cm)	6" (15.2 cm)
Knee clearance under sit-down work area	27" (68.6 cm)	28" (71.1 cm)
Drawer load support at full open position	100 lbs (45 kg)	100 lbs (45 kg)
Aisle width between casework	5' (1.5 m)	5-6'(1.5-1.8 m)
Aisle width between casework and wall	4' (1.2 m)	5' (1.5 m)

5 Storage (Refrigerated and Nonrefrigerated)

Because storage is measured in cubic feet, any discussion of storage soon becomes a discussion of space. Items are stored because there is, or was at some time, a perceived need for the item. Stored items should be readily accessible for use. This section identifies some issues that influence the amount and kind of storage required.

Because of the variable nature of laboratory operations, the determination of the amount and type of storage space needed may be more of an art than a science. These variables include the types of testing services (manual or automated chemistries and the spectrum of microbiological/immunologic testing), the volume of testing, the total space available to the laboratory, the number of employees, and work flow patterns, to name only a few. Although decisions may require a more subjective than objective analysis, it is important that the administration and staff give a lot of thought to storage requirements with respect to more than just square footage. The outcome of this analysis will determine the actual space needs, but laboratory records should be analyzed to obtain the following information, which should also be included in the Space Program Statement discussed in Section 3.7.1:

- Average annual workload for each operating section over a 5-to-10-year period.
- Projections for changes in workload (up or down) based on changing technologies or menus of services.
- Annual orders for supplies, reagents, and chemicals.

- Actual annual usage of supplies.
- Lead time required to obtain orders from suppliers.
- Shelf-life of testing materials and temperature considerations.
- Use of pre-prepared reagents versus in-house preparation from bulk supplies.
- The volume and nature of hazardous substances used.

5.1 Quantity: Determining the Amount and Kind of Storage Space Needed

Several well-tried methods are available for determining the amount and kind of storage space needed. Similar methods exist for estimating the rate of usage of supplies and the subsequent timing of reordering. The following text describes several of these methods.

5.1.1 Stockpiling vs. "Just-In-Time"

There is a growing trend to reduce the amount of space used for storage in virtually every industry, with the manufacturing sector leading the way. Stockpiling months worth of components needed to produce a product, be it an automobile or a clinical laboratory test result, is being replaced by a "just-in-time" (JIT) system. With even giant manufacturing plants now often keeping only a 5-day inventory, there is no reason that laboratories cannot also become more space conscious. Careful review shows that, in some cases, it may no longer be necessary to keep more than a 2-week supply available for 75 to 95% of the items used in most laboratories. However, the final ordering decisions as to "what, how much, and when" may be determined by economic or other issues specific for each ordered item within an institution. Each laboratory's experience with the "turn around time" by various suppliers also must be considered when adapting a (JIT) system.

5.1.2 Materials Management System for Ordering

Effective use of a basic materials management system can reduce significantly the amount of material that is ordered and thereby stored in a laboratory. Materials management is a system for controlling costs, inventory, distribution, paperwork, and other functions related to supplies, services, and equipment. An effective materials management system works together with an effective inventory control system.

5.1.3 An Inventory Control System For Allocation of Storage Space

It is important to include the inventory control philosophy of the laboratory in the program statement discussed in Section 3.7.1 because it can alter space requirements. Changes in inventory control can alter space needs. For more information on setting up an inventory control system, see NCCLS document GP6—*Inventory Control Systems for Laboratory Supplies*.

In many ways, modern laboratories, clinical laboratories in particular, exhibit some of the finest examples of modern manufacturing technique. Products, in this case laboratory results, are produced on demand. Laboratories are capable of switching rapidly from the production of one product to another as demand changes. They also do high-speed, low-cost, full- automation manufacturing (e.g., chemistry and hematology profile analyses) in the same environment as custom fabrication for low-volume orders (e.g., most other laboratory analyses). What has not yet been employed is the JIT ordering system, which could significantly reduce overall material costs as well as on-site storage requirements. The calculation of the economic order quantity (EOQ) and the reorder point (ROP) is one way of arriving at a JIT ordering estimate.

5.1.4 Kanban System [10] for Initiating Orders

The Kanban, or "pull system" (from the Japanese word meaning "card"), is one of the simplest, and therefore one of the most popular systems for keeping supply stock at an appropriate level. The first step involves determining the amount of a supply that must be kept available using all of the considerations listed in Section 5. An area, which could include one to several drawers or shelves, is allocated for each supply item. When the supply of an item drops to the point where it is necessary to order more of that item, as indicated by the EOQ and the ROP estimates, an order is generated for more supplies. This ROP indicated by placing pieces of tape of different colors on each shelf so that

it is obvious when the shelf is empty. This system works especially well in conjunction with a JIT system. Many laboratories actually use a Kanban system without realizing it: When they notice that the stock is getting low, they order more supplies.

An analysis of the data available from the items listed in Section 5 should lay the groundwork for an estimation of the storage space needed for the laboratory. Laboratories storing materials/supplies in bulk quantities will obviously need more space than those using premade or working stock only.

Laboratories using hazardous materials and storing these in bulk quantities will not only need specially designed space but also proper ventilation. If the storage area is provided with a construction design that has at least a 1-hour fire resistance rating, inside storage areas that have 150 sq ft (13.8 sq m) of floor space may contain up to 2 gal of flammable or combustible liquids per square foot (7.6 L) of floor area.[11,12] This storage can be increased to 5 gal per sq ft (18.91 per 0.092 sq m) with installation of an automatic fire extinguishing system.[13] For the most up-to-date information, consult local and national codes.

Braybrook[14] suggests that storage space convenient to work areas should account for 12 to 17% of the net square footage of the laboratory space and central storage should account for 5 to 7% of the net square footage.

5.2 Quality: Determining Temperature and Humidity Limits or Other Special Characteristics

The quality of storage space is determined by the nature and volume of the items to be stored. A laboratory with an inventory of media, dry chemicals, dyes, and other reagents can use almost any conventional space available in or adjacent to the laboratory bench areas. When the volume of inventory could be consolidated, such a laboratory could also centralize storage anywhere in the building.

5.2.1 Location of Storage Areas

By the nature of the testing work done, laboratories may need to store items that are potential chemical, physical, or biological hazards. However, laboratories that carry significant inventories of acids, caustic solutions, organic solvents, and/or other potentially hazardous materials must meet fire and other safety standards for storage. Radioactive sources, compressed gases, and reactive compounds must be stored carefully and checked periodically to ensure that a hazardous situation is not developing. Care must be taken to store general stocks of these materials away from laboratory and office areas. If an accident (e.g., fire or explosion) should occur, exit areas must not be blocked. Fire walls and other construction barriers should be in place to prevent damage, including ventilation contamination, from affecting the rest of the laboratory. Areas for the storage of hazardous substances should be properly equipped for the drainage of spillage. If drainage normally goes to a septic tank, then special provisions should be made for capturing the spillage of hazardous substances. Large containers must be stored at floor level or on low shelves. Special storage cabinets are required for the storage of flammable liquids.

5.2.2 Temperature and Humidity

Temperature requirements in rooms as well as refrigerators and freezers must be adjusted to meet the conditions for storage recommended by the manufacturer. Humidity levels below 20% cause build-up of static electricity. Humidity levels above 50% may cause condensation to develop. Room temperature, as may be specified by manufacturers for product storage, refers to the range from 18 to 26 °C, which is considered to be a comfortable room temperature range for human habitation. Temperatures ranging from 2 to 8 °C are considered refrigeration storage, and freezer storage is -20 °C or colder. Items that should be stored for months, such as blood bank products, are typically stored at temperatures below -30 °C. Indefinite storage, as with tissue samples and embryos, generally requires liquid nitrogen.

Because freezers, refrigerators, and other equipment can generate considerable heat, the size of rooms in which they are located and the number of these appliances must be considered in determining ventilation and air circulation needs.

Again, laboratory management must know the volume of those materials that require refriger-

ation, freezer storage, or room-temperature shelf storage before they can determine the actual amount of storage space needed and the environmental conditions under which storage must be provided. This determination will also affect discussions about power requirements for the laboratory.

Selection of storage space may be influenced by the need to balance considerations of inventory control against giving laboratory staff ready access to supplies, media, and reagents. Will the best use of space for your laboratory storage needs direct you toward centralized or decentralized storage areas?

5.2.3 Record Storage

Despite great strides toward getting laboratory records into electronic media instead of paper, the typical laboratory must continue to store paper records where they can be retrieved readily. Generally, clinical laboratories are required to keep all patient results and quality control documentation for two years. Blood banks must keep their records much longer. Therefore, users are encouraged to refer to local, state, and federal regulations for information about user storage requirements, particularly as they apply to minors.

It is not unusual for a 500-bed hospital laboratory to generate enough paper records to fill 32 linear feet (9.75 m) each year. Even research laboratories must keep detailed records of what is done each day. Bulk records can be stored in boxes and need not be kept in the laboratory if a more remote storage area can be found.

Particular care should be taken to note what records are stored where to ensure that they do not get discarded accidentally. Research laboratory workbooks are often required to establish first discovery in patent cases, and loss of some clinical laboratory records could violate federal or state laws and accreditation requirements.

5.2.4 Sturdy Storage

Because paper records can take on the weight characteristics of a 4-foot (1.2 m) long, 12-inch (30.5 cm) thick log, it is not readily apparent when a three-ring notebook is placed on a shelf that the accumulated weight on a 4-foot (1.2 m) long shelf can exceed 150 lb (67.5 kg). Some shelving may not be up to the task, which may lead to sagging or physical collapse of the shelf or the entire shelving system. Storage shelving should be securely fastened to the wall or another sturdy support system. Potentially hazardous liquids or reactive chemicals should be stored only on bottom, floor-level shelves. To keep shelves and their contents from falling forward if shelving is not attached to the wall, consider using shims under the front base. Seismic code requirements should also be considered in the design of storage shelving systems.

5.3 Control

5.3.1 Access Control

To facilitate better materials management and to limit the risk to personnel when storing hazardous materials, access to storage areas should be controlled. To maintain proper inventory control, there must be some materials management system in place to ensure that when supplies are removed there is some way to determine if more supplies should be ordered, perhaps using a Kanban system as described in Section 5.1.4. If the number of locations drawing from the same stock increases and control is not maintained, nearly all material management systems become compromised to the point that further decentralization is necessary.

5.3.2 Environmental Temperature Control

For occupied areas, local heating, refrigeration, and air conditioning standards[d] should be incorporated into the construction and design of the laboratory.[15] A centralized heating and air conditioning system should be used. Ideally, each room should have its own controls. This is especially important for storage of materials within a large, centralized storeroom.

5.3.3 Equipment Temperature Monitoring

Failure of refrigerators and freezers to maintain their set temperatures can be a catastrophic event. Such an event may destroy years of archived samples or hundreds of thousands of

[d] For example, standards of the American Society of Heating, Refrigeration, and Air Conditioning Engineering, 1791 Tullis Circle, N.E., Atlanta, GA 30329.

dollars of diagnostic test reagents. It is, therefore, desirable that all laboratory refrigerators and freezers be equipped with independent temperature-monitoring systems with alarms that do not derive their power from the same circuit breakers as the monitored devices. This can be accomplished by using either a small, battery-powered system or a remote monitoring system, some of which can monitor over a dozen refrigerators or freezers simultaneously. Some systems automatically place a phone call if temperature limits exceed prescribed limits and print graphs on demand that show historical temperature readings. The temperature-monitoring system should be located in a part of the laboratory that is occupied most of the time. Consideration should also be given to putting equipment on emergency back-up systems.

5.4 Supply and Removal of Storage

Whether a centralized or decentralized inventory control system is used when determining access needs to items in inventory, both short- and long-term needs should be considered. This applies to the entire laboratory operation, not just the storage space.

5.4.1 Nonrefrigerated Storage

It is recommended that supplies and records that are not required in the laboratory area are stored in an accessible location outside the working laboratory area and should be available within a reasonable amount of time.

5.4.2 Refrigerated Storage

Walk-in refrigerators and freezers provide large, centralized storage areas for materials in need of temperature-controlled storage. They also provide the capacity for security for reagents or specimens, particularly for those laboratories involved in drug, alcohol, or forensic testing. However, the presence of walk-in space does reduce flexibility if it ever becomes necessary to reconfigure the laboratory because of changes in workload or test systems.

Except for large laboratories or research laboratories that need limited access and special storage temperatures for reagents and other test materials, moveable refrigerators and freezers are perfectly suitable for laboratory use. Regardless of the type chosen, if they are to store volatile materials, they should be explosion proof.

Whether solid or glass doors (or any other appropriate transparent material), or lid tops are used for refrigerators and freezers is a personal choice. Some laboratorians believe it is advantageous to look in before entering to locate what they want, thereby reducing the time the refrigerated unit is opened.

Because of the ever-changing configuration of laboratory products and packaging provided by manufacturers, adjustable shelving is preferred for all storage. Marketing representatives sometimes place a higher premium on eye-pleasing packaging as a competitive advantage than the practical storage considerations of the laboratorian. For those who must purchase supplies on a low-bid basis, changes in package sizes can create a significant problem if shelving is not adjustable.

5.5 Storage Expandability

5.5.1 New Construction Storage

For those fortunate enough to be planning new construction or who are planning a move to an older building that requires substantial remodeling to accommodate laboratory operations, planning for future expansion is not easily done. Most new laboratory construction today is planned with about a 20 year life expectancy for the facility. However, even the best of plans may be modified if cost estimates are found to exceed available financial resources. Owners of private laboratory operations and politicians who fund public laboratory operations often will not support planning for growth or emergencies. When they see there will be some empty rooms or (perceived) excess storage areas, these areas often are eliminated. Several examples exist where new laboratories were built to meet only existing needs and within 2 to 5 years it became necessary for the laboratory to lease extra space away from the main facility or to build a wing onto the main building. Thus, if the laboratory is a part of a larger health care service, the laboratory should be located next to an area that will support future expansion.

If storage areas are located some distance from the laboratory, this storage space becomes a prime "target" for other units in the facility that

may be looking for available space to expand their operations. Therefore, in shared buildings, try to keep laboratory storage space and offices adjacent to or near the operating laboratory spaces.

5.5.2 Existing Space Storage

When new construction is not possible or feasible, the same general rules apply. Keep as much of the laboratory together as possible. In shared facilities, consider trading internal building space for external so that future remodeling will be easier and cheaper. Heating, air conditioning, and electrical or other utility services must be designed for easy and economical expansion. In older buildings, complete upgrading of these elements may be required, as well as planning for future growth needs. (Because expansion planning applies to every facet of the laboratory facility, not just storage, this section may appear to be redundant.) However, the development of a rational storage space plan is completely dependent on actually doing those things listed in Section 5. The addition of just one new instrument, water bath, incubator, or laboratorian can affect temperature and ventilation within the entire laboratory, as well as add to the power demands of the facility.

5.5.3 Decentralization of Storage

Considerable decentralization of storage-to-work areas is possible if supplies on hand can be kept under control through good ordering practices. Such decentralization can be part of a risk management program should a problem develop in one part of a laboratory. Moving refrigerator and freezer storage close to the work areas can improve productivity. Refrigerators with glass doors can minimize the number of times refrigerator doors are opened. Expansion of refrigeration and freezer storage space may be limited by power, ventilation, and space constraints because all of these are consumed in the process. For example, six 4' x 3' x 6' (12 m x 0.91 m x 1.8 m) (L x W x H) external dimension, double- door, 120-V refrigerators could consume 40 to 60 A of current; 48,000 to 72,000 W of power; and 72 sq ft (6.6 sq m) of floor space.

5.5.4 Expansion of Walk-In Refrigeration Storage

It is now possible to construct and relocate walk-in refrigerator storage space relatively easily using modular insulated panels, often in 4- x 8-foot sizes, that fasten together. These systems permit the construction of an insulated box to which a door and refrigeration system can be added to complete the installation. The walk-in refrigerator is relocated by reversing the assembly process, thereby eliminating the disadvantage in flexibility traditionally associated with constructed walk-in refrigerators.

5.6 Code and Safety Issues

Architects and building contractors should be able to offer advice about state and local ordinances that govern the storage and handling of hazardous materials, as well as fire, electrical, and plumbing codes. Because of the variability of these from one community to another, local codes and ordinances should be checked. Most state and local codes are based on national standards; however, because these standards are often minimal, local codes may be more stringent. Sometimes special thought must be given to these safety issues regarding storage during construction. For example, if cabinetry is to be ducted to the exterior, the ducting material must offer at least an equal level of protection as the cabinet itself. [11,12,16]

In the U.S., the most recent version of the following guidelines and standards for laboratories should be considered while planning and setting up storage facilities in addition to the heating, refrigeration, and air conditioning engineering standards referenced in Section 5.3.2.

- *Designing a Laboratory, 1989. Available from the American Public Health Association, 1015 15th St., N.W., Washington, DC 20005.*
- *Biosafety in Microbiological and Biomedical Laboratories, HHS Publication No. (CDC) 93-8395. Available from the U.S. Government Printing Office, Washington, DC.*
- *National Fire Protection Association Standards. Available from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.*
- *The Storage of Blood and Blood Products. Available from the American Association of Blood Banks, 8101 Glenbrook Road, Bethesda, MD 20814.*
- *The Uniform Building Code. Available from the International Conference of Building Officials, 5360 South Workman Mill Road, Whittier, CA 90601.*

- *The Uniform Fire Code. Available from the International Conference of Building Officials, 5360 South Workman Mill Road, Whittier, CA 90601.*

- *OSHA Standards for General Industry. Available from the Occupational Safety and Health Administration, U. S. Department of Labor, U. S. Government Printing Office, Washington, DC 20402. Published in the Federal Register, 29 CFR 1910, December 6, 1991.*

- *Americans With Disabilities Act of July 26, 1990, Public Law No. 101-336, 42U.S.ss 12101 et. seg. (ADA).*

- *NFPA-101, Life Safety Code, 1991 edition. Available from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.*

The Americans With Disabilities Act (ADA) requires employers to accommodate personnel with special requirements for access to work areas. In case of an emergency, laboratories should make provisions for the easy exit of employees with disabilities. Also, hallways, aisles, work bench heights, and other impediments to persons covered by the ADA must be modified to meet the needs of persons with disabilities.

5.7 Storage Fundamentals

Basic consideration for final determination of actual space requirements in net square feet must be based on the answers to the following questions:

- Why is the material stored in the working laboratory area? If items stored in the working laboratory area have not been used in the past year, laboratory organization and productivity might increase if the items were disposed of or put into a long-term storage area. If not used for over a year, disposal is preferable to moving to another storage area.

- What is the volume (amount) of material to be stored? The laboratory should be prepared to logically defend why supplies are not automatically drop-shipped so that a running 2-to-4-week supply, rather than a 12-week supply, is kept in the laboratory.

- What is the configuration of these materials (e.g., size and shape of bottles and boxes)? Can materials be ordered in a more convenient size?

- How much is to be stored as inventory and how much for working amounts? Laboratories seldom need to keep large inventories of items because arrangements can be made to get nearly everything shipped when needed with whatever lead time is necessary.

- Where is working stock prepared from stock quantities? Stock supplies can be bulky and dangerous to handle. Therefore, it is preferable to limit the preparation of working solutions to as few persons and locations as possible.

- Which reagents must have special fire-retardant or other hazardous retardant storage? Storage room for hazardous/ volatile/corrosive materials should have windows so that in case an accident occurs, the victim can be seen. Better yet, large volumes of such materials should not be handled by one person. A second should be available to provide assistance or call for help.

- What is the total volume of the reagents to be stored?

- What is the logical arrangement in storage for supplies and reagents (wall-to-ceiling storage or shoulder height)?

- To whom should stock supplies be accessible (e.g., will a supply clerk provide supplies to staff or will all staff members have access to the supply area)?

- How many persons might be in a storage area at one time?

- How do storage areas fit into traffic pat-terns for laboratory staff and other health providers located in the same building? One of the best ways to significantly increase storage space is to use overhead storage areas. A single 48 x 12 x 36-inch (121.9 x 30.5 x 91.4-cm) (L x W x H) storage unit supplies 12 cu ft (3.4 cu m) of storage space.

5.8 Calculations

When these questions have been answered, a reasoned approach to calculating the exact square footage needed can be undertaken. A cross-check for the figures arrived at by the determination of the volume of supplies and reagents, and the space for shelves and aisles, can be made by applying the percentage for-

mula mentioned in Section 5.1.4.[14] If the two sets of numbers are reasonably close, then the calculations are likely to reflect the storage requirements.

5.8.1 Forecasting Usage of Supplies

Example:

A laboratory ordered 20, 30, 40, 50, and 60 units in the last 5 months. The laboratory initially predicted that 55 units would be needed in the last month. How much should be ordered now?

Methods of Forecasting

Moving Average: (Good)

Where average use over the last 3 months = 50.

Forecasting: (Better)

New Forecast = (0.9 · Old Forecast) + (0.1 · Last Month Usage)

New Forecast = (0.9 · 55) + (0.1 · 60) = 55.5

5.8.2 Economic Order Quantity (EOQ): Knowing How Much To Buy

The EOQ is the level that balances holding (or carrying) charges, which increase with the amount of inventory carried, and the order costs, which decrease with the amount ordered.

$$EOQ = \sqrt{\frac{2AS}{UI}}$$

$$= \sqrt{\frac{2 \cdot 100 \cdot 10}{100 \cdot 5}}$$

$$= 4 \text{ kits/order}$$

Where:

A = Annual usage in units
Example: 100 T4 assay kits

S = Cost to order
Example: $10 to place an order

U = Unit cost
Example: $ 100/kit

I = Inventory carrying cost
Example: $ 5

5.8.3 Reorder Point (ROP) Knowing When To Buy

ROP = Lead Time Supply + Safety Stock

$= F(LT + RT) + SS$
$= 4(0.5 + 0.25) + 2$
$= 5$ kits.

Where:

F = Forecasted EOQ
Example: 5

LT = Lead time needed
Example: 14 days (0.5 mo)

RT = Review time needed
Example: 7 days (0.25 mo)

SS = Safety stock required
Example: 2 kits.

5.9 Minimum and Recommended Criteria

These criteria will be modified by the laboratory's ordering patterns and the supplier's capacity to deliver in a timely manner. Other relevant factors include cost and budget constraints. Some laboratories obtain price advantages by buying in bulk. They may buy all their glassware, media, chemicals, and miscellaneous stock on a quarterly basis. This arrangement requires a large, centralized storage space and an inventory control program. Other laboratories purchase by contract for periodic delivery and pay "up front" for larger discounts. This practice does not require a large, centralized storage space because regular delivery can be controlled to meet workload requirements. It is this latter group of laboratories for which these recommendations may be most appropriate.

To save lump sum outlays, other laboratories may purchase on an "as-needed" basis; however, this may be more costly in the long

run. These laboratories will need a minimum of storage space, particularly if they purchase working amounts of supplies in contrast to stock reagents for in-house preparations. The danger in this practice is that it leaves the laboratory vulnerable to unforeseen breakdowns in the supply-delivery system. Thus, laboratories are well advised to provide storage at the recommended levels (Table 8).

Table 8. Criteria for Laboratory Storage

Overall Storage Capacity (Working Days)	Minimum	Recommended
Reagents, media, other test materials	2 days	7 days
Disposables (gloves, pipets, wipes)	5 days	10 days
Reusable glassware	10 days	20 days

Total storage area (e.g., room temperature and refrigeration/freezer) should be two times the cubic footage of the space producing laboratory results (e.g., work surface for manual tests assuming a height of 1 ft (0.3 m) or instrumental system L x W x H) just to support the technical work done. For example, a clinical chemistry analyzer with dimensions of 6 x 3 x 4 ft (1.8 x 0.91 x 1.2 m) would need about 72 cu ft (1.97 cu m) of storage capacity, the amount in 8 ft (2.4 m) of base casework (8 x 2.5 x 3 ft [2.4 x 0.76 x 0.91 m] or 60 cu ft [1.66 cu m] and two double-wide refrigerators (40 ft cu ft each [1.2 cu m]). A 6 x 3-foot (1.8 x 0.91 meter) manual work area on a bench would need 36 ft cu ft (11.0 cu m) of storage space for supplies. The amount of record storage needed depends on the amount and length of time paper records will be retained.

6 Ventilation In Laboratory Design

Ventilation is one of the most important elements in the design of a laboratory, and one of the most expensive. Indeed, the single largest demand for energy in the laboratory comes from the air-handling system. Proper ventilation not only rids the laboratory of noxious and/or toxic odors and vapors, but it also promotes proper equipment functioning, maximizes temperature control, provides for the comfort of personnel, optimizes test performance, and facilitates a safe environment for personnel and patients both inside and outside the laboratory. Because ventilation is so important to the successful design of a laboratory, and because it is such an expensive component, it is vital that monies for ventilation be budgeted appropriately. The following information provides guidance on how to develop specifications for proper laboratory ventilation.

6.1 Quantity

Air-exchange rates vary widely in the literature. For example, according to the American Institute of Architects' *Guidelines for Construction and Equipment of Hospital and Medical Facilities*,[17] the minimum total air changes per hour is six. This, however, is out of date when one considers the computerized equipment used in today's laboratories that allows considerably more heat into the environment than previous equipment. In addition, concerns about indoor air pollution are causing an upward revision of the recommended air exchanges needed to create a more wholesome environment. However, these data are only guidelines for design. Local and state building codes will establish the minimum air-exchange rates.

Current thinking advocates a minimum of 12 air exchanges per hour in general technical areas where vapors and biohazards are used, with 16 exchanges considered more appropriate in some areas. In the design of the heating, ventilating, and air-conditioning (HVAC) systems for the laboratory, take care to thoroughly understand the use to which each room will be put; the ability or capacity of the air-handling systems to cool, heat, humidify (or dehumidify), and cleanse[7] the air; as well as the size of the space involved, the location of the laboratory, HVAC equipment within the facility, building constraints, and potential future needs.

Many laboratories today are built with 100% outside air/exhaust (also called single-pass air). Some architects (and organizations/administrations, for financial reasons) are reluctant to use single-pass air because of energy-conservation concerns. There are, however, several reasons why 100% outside/exhaust air hand-ling is the most desirable:

- Rooms that contain fume hoods and/or biosafety cabinets, where biohazardous materials are handled, or where animals are housed (rare in clinical laboratories) all require a single-pass air system.

- Rooms where autopsy and histology procedures are performed have a high level of fume production and should have special ventilation requirements. Also, gross pathology and other anatomical procedures may require 100% outside air exchanges. Downdraft ventilation should also be considered.

- Laboratories that are built on the "open-lab" concept often support both hazardous and nonhazardous operations.

- To prepare the laboratory air for recirculation, additional equipment may be used to heat or cool, dehumidify, or filter the air, which might negate any energy cost savings gained by installing a recirculating-type HVAC system.

To evaluate the efficiency of air handlers for each laboratory, consideration should be given to the development of performance standards for monitoring air exchange capabilities on a periodic basis.

6.2 Quality

For the purposes of this document, "air quality" is described as an atmosphere where the temperature, humidity, contaminant level, and vapor level are known and maintained.

Temperature-control design criteria are affected by many factors, not the least of which are the operational tolerances of the equipment in the laboratory. A critical element of any laboratory design is the identification of the equipment that will be used in the area. Particular attention is given to computerized equipment, which produces considerable heat and usually has limiting operational tolerances.[7] Other important elements are the number of persons that will be working in a room at one time and the influence of the exterior environment (summer/ winter factor). Only when these data are known, can the mechanical engineer or industrial hygienist design the air-handling system to maintain appropriate temperature tolerances.

Most laboratory equipment does not have significant humidity requirements and accepts a wide range of tolerances—from 30 to 70% in some cases—which is not difficult to maintain in most buildings.[16] However, in northern climates during the winter, because the outside air is cold, some humidification may be required. Two types of humidifiers may be considered, depending on the cost: Steam injection and water spray humidifiers.[7] Because of the potential for harboring micro-organisms, reservoir-type water spray humidifiers should not be used.[16]

Air that is contaminated by toxic or hazardous vapors, noxious odors, or biologic entities must be contained and eliminated.[18] Contaminated air is handled by various types of fume (vapor) hoods and biological safety cabinets.

There are many types of vapor hoods available for laboratories, including[2]:

Canopy hood: To remove odors, vapors, heat and humidity, canopy hoods should be placed only over large equipment, usually within chemistry, histology, or sterilizer areas. Because vapors may be drawn past the worker's breathing zone before being vented, canopy hoods should not be used over areas where personnel routinely work. In addition, to

Backdraft, slot, or spot hoods: These hoods are extremely effective in pathology/histology areas where personnel work in close proximity to toxic/noxious vapors; for example, while

dissecting, staining, and coverslipping. While similar to canopy hoods, they use a large quantity of air, vapors and odors are not drawn past the user's face. These hoods are placed at the back face of the work bench, usually not maintain adequate exhaust velocity, canopy hoods require a significant quantity of room air. Vapors that are heavier than air can be removed effectively only with considerable exhaust pressure, and some vapors tend to disperse in the air before they are "exhausted." Canopy hoods should not be used to "exhaust" toxic or flammable vapors.

more than six inches above the back splash. They are effective in removing the heavier-than-air vapors that are created in histology areas. The planner should provide adequate service access per the manufacturer's recommendations.

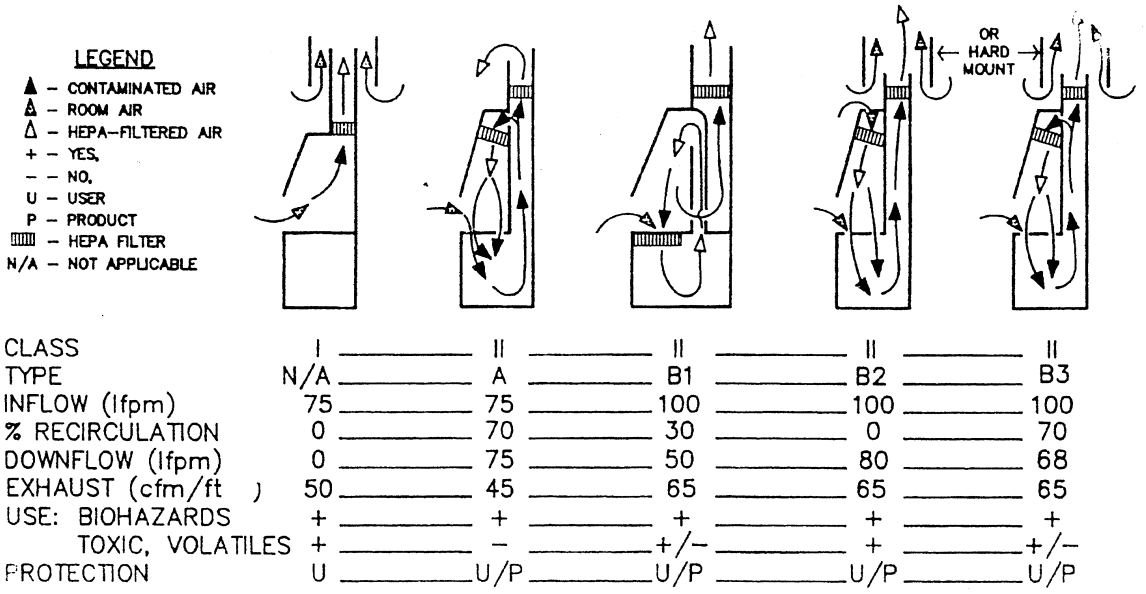

Figure 13. Air flow characteristics of Class I (negative pressure) and Class II (vertical laminar flow) biological safety cabinets (cfm = cubic feet per minute per width of face opening). From *Designing a Laboratory*. Copyright 1989 by the American Public Health Association. Used with permission.

Conventional hood: This type of hood, which is used for the removal of chemical vapors, includes an overall enclosure with an adjustable safety glass sash and an exhaust blower-motor at the end of the system, which is used to maintain a negative pressure.

Exhaust ducts from each laboratory unit must run their separate courses to a point outside the building, and, at the roof level, they must be located away from and down-wind of fresh air-intake louvers. Exhaust ducts from laboratory hoods and other exhaust systems within the same laboratory unit are permitted to be combined within that laboratory unit. However, no air "exhausted" from any laboratory hood may be recirculated.[19] The airflow rate of a typical conventional hood ranges from 60 to 125 linear feet per minute (lfm) (0.30 to 0.64 meters per second) when the opening of the sash is approximately halfway open.[7]

The removal of infectious, biohazardous material from the air is paramount to protecting the health of laboratory employees and patients. Information regarding specific standards for the various types of hoods should be obtained from specialized sources.[20]

Biological Safety Cabinets (BSC): Biological safety cabinets contain potentially infectious material within the work chamber and protect the worker from aerosols. There are two general classes of BSCs: Class I and Class II. A Class I BSC operates strictly on negative pressure. Air is pulled in from the room and "exhausts" out the vent. The air quality is the same as the quality of the surrounding laboratory air, but the worker is protected from aerosols. This BSC must be vented to the outside. Class I biosafety cabinets are rarely used in clinical laboratories today. Class II cabinets are divided into four subgroups, A, B1, B2, and B3 (see Figure 13). The planner should consult specialized sources for information regarding tuberculosis and other aerosol pathogen considerations in laboratory design.

Because of the use of high-efficiency particu-late air (HEPA) filters, vertical laminar flow hoods (Class II BSCs), provide a low-particulate working environment within the chamber. When appropriate techniques are used, both the worker and the product inside the cabinet are protected from contamination. Class II BSCs are seen most often in clinical laboratories. Class A, B1, and B3 BSCs recirculate from 30 to 70% of the air through HEPA filters within the cabinet.

Class IIA BSCs need not be vented to the outside. Class IIB cabinets are usually vented to the outside. It should be remembered that Class IA, B1, and B3 BSCs, which recirculate air, should not be used with toxic, flammable, or explosive materials because of a potential buildup of hazardous materials within the cabinet or, in the case of BSC IIA, because materials are discharged back into the laboratory environment. While Class B2 cabinets exhaust all air, after filtration, to the outside, they do require a high-air demand, approximately 700 to 1,200 cfm, (0.33 to 0.57 cu m per second) with concomitant incurred energy requirements and operating costs.[7]

Also note that only a flameless loop incinerator should be used inside BSCs because a flame, especially from a large burner, may create turbulence and disrupt the downward laminar airflow.[7]

The most common BSCs in use in laboratories today are Class IIA and B3. The velocity of inward airflow varies from a minimum of 75 cfm (0.04 cu m per second) for Class I and Class IIA BSCs to 85 to 100 cfm (0.04 to 0.05 cu m per second) for all Class IIB cabinets.[7]

Some laboratory tasks, such as media preparation, require a sterile field. A "clean room" is expensive to build and to maintain. Therefore, a laminar flow hood, which is used in the pharmacy for the sterile preparation of intravenous fluids, may be useful for a laboratory. Air flows outward from the hood and protects only the product from the environment. Because personnel are not protected, laminar flow hoods cannot be used when personnel are working with infectious, toxic, or otherwise hazardous materials.

6.3 Control

Regulation devices: There are a number of control devices that should be accessible to appropriate personnel.

Thermostats: Because equipment varies from section to section, producing varying amounts of heat and having different operational tolerances, *each laboratory area should have its own thermostat control.* In addition, as equipment is added or removed, temperatures may need to be adjusted. It is not required, however, that control of the thermostats reside with the laboratory staff.

Other controls: There are other supply air control devices that should allow access for routine maintenance, performance testing, and other service activities. These include pressure-independent volume control dampers, variable air volume (VAV) dampers, reheat coils, humidifiers, filters, and other control dampers.[7] In addition, each air-distribution system should have at least one manually operated accessible means, installed within an approved location, to stop the operation of supply, return, and, in some cases, exhaust fans in an emergency.[19] Some controls may be built into other operating systems.

For example, an interlock device could connect lighting to exhaust fans so that when personnel are working in the area, the exhaust system is on and when the laboratory is closed and lights are off, the unneeded exhaust system is off; thus saving energy. Care must be taken to ensure that this lighting/exhaust system is off when not in use.

Air-handling systems: The size and number of air-handler units for a laboratory area depends on many factors: the size and volume of the area to be controlled; the heat production and operational tolerances for each piece of equipment in use in the area; the number of personnel; the presence and characteristics of fume hoods and biosafety cabinets; and so on. Each space is unique, depending on the previously-mentioned characteristics, and a mechanical engineer must take them all into account when determining the type, size, and placement of air handlers. In addition, in smaller laboratories, the air-handling unit may be shared with another department with substantially different ventilation requirements. To provide for the differing ventilation needs of each department, it is important to set the supply unit to the temperature of the department that requires the most cooling (usually the laboratory) and use booster coils to temper the air for the remaining areas. Alternatively, the proper application of VAV boxes in the supply air can eliminate the need for booster coils.

6.4 Supply and Removal

Because today's clinical laboratory handles significant amounts of potentially biohazardous

materials along with toxic and vaporous chemicals, recirculated air cannot be used except in an area where no chemicals or "biologicals" are handled— such as an office.

There are generally two ways of providing "single-pass air" ventilation.

- One-hundred percent of the air comes into the laboratory from the outside and 100% of the air is "exhausted" to the outside.
- One-hundred percent of the air is "exhausted" to the outside; however, the supply air may include some recirculated air from other nonhazardous areas that are permitted to recirculate air.

The latter approach enhances energy-conserving capabilities,[7] but it requires careful planning.

How and where air moves within a space (air distribution) is dependent on placement of air-supply points and discharge points, as well as air-diffusion techniques. In laboratory areas, such as offices or nontechnical support spaces, the "air-diffusion pattern" is quite common (Figure 14). Air is distributed through ceiling-mounted vane diffusers at a relatively high velocity, about 25 fpm (0.127 meter per second) or greater, which creates and maintains air velocity and movement patterns appropriate for the space.[7]

Laboratory areas that deal with aerosols or materials considered to be highly hazardous usually require a single ceiling supply point and multiple high- and low-exhaust points for both ordinary air exhaust and vapors that are heavier than air (Figure 15).[7]

When fume hoods, canopy hoods, or BSCs are to be used within an area, air-distribution techniques are somewhat different. Supply air is delivered to the space by low-velocity, high-aspirating devices with the air intake located remote from an exhaust point, such as a fume hood. These diffusers produce a piston-like air motion at low velocities toward the point of exhaust so that turbulence at exhaust devices is minimal (see Figure 16).[7]

Laminar flow hoods (in clean areas) require that supply and exhaust air velocities and air flow patterns be designed so that they do not interfere with the airflow of the hood. Commonly, there are multiple ceiling supply points and multiple low-exhaust points to minimize pockets of airborne particles.[7]

In addition to providing for appropriate air exchanges, air flow into and out of an area is particularly important for a clinical laboratory. The overriding rule is that air should move from "clean to less clean" areas.[17] In other words, laboratories in general should be at a negative pressure to the corridors that serve them. Volatile and biohazardous areas within the laboratory should have air flowing into them from less hazardous areas (see Table 9) [7]

The need to maintain directional airflow at every instant and the magnitude of airflow needed will depend on individual circumstances. For example, “clean” rooms might have very strict requirements, while teaching laboratories might only need to maintain directional airflow during certain activities or emergency conditions. In the latter cases, one would simply use the appropriate offset to maintain directional airflow as needed and operational procedures during emergencies (i.e., close doors during a chemical spill).[21]

6.5 Expandability

The size of the air-handling equipment and the design of supply air duct work must include expansion capabilities. For both the air-handling unit and accompanying duct work, include a 15 to 25% growth in exhaust air quantities in any calculation. Future needs assessment should include design concepts that address the issues of flexibility, reliability, and potential retrofit in the laboratory air-handling systems.[7] For example, energy management systems are being retrofitted into air-handling systems because energy conservation and its concomitant cost savings are of increasing concern. If the energy-management system is retrofitted without considering the specialized air-handling requirements of today's laboratories, the effectiveness of the ventilation systems could be seriously compromised.

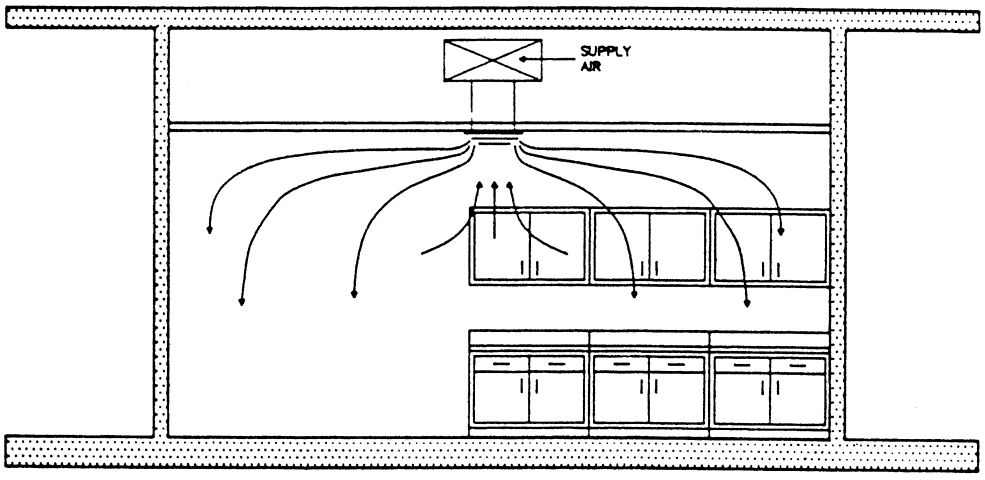

Figure 14. Air diffusion pattern. From *Designing a Laboratory.* Copyright 1989 by the American Public Health Association. Used with permission.

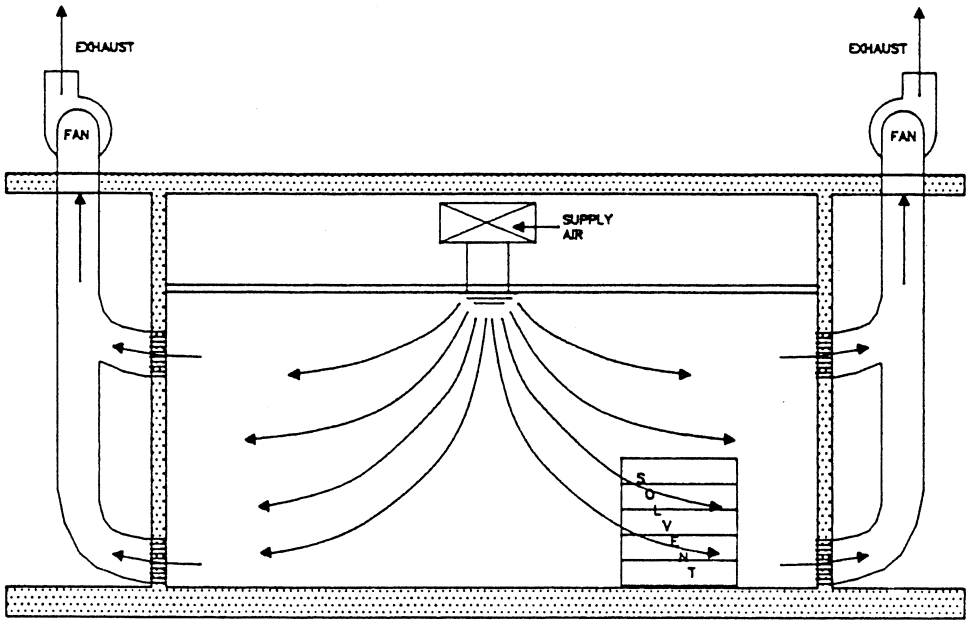

Figure 15. Air distribution for a solvent storage and dispensing area. The area has a single ceiling supply point and multiple high/low exhaust points. From *Designing a Laboratory.* Copyright 1989 by the American Public Health Association. Reprinted with permission.

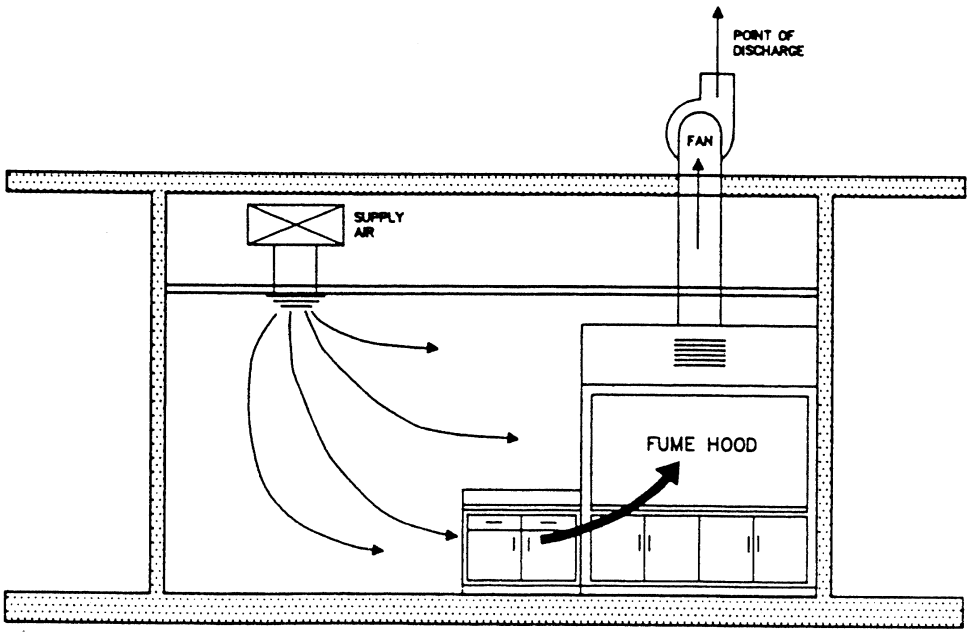

Figure 16. Air distribution for a laboratory with a fume hood. From *Designing a Laboratory.* Copyright 1989 by the American Public Health Association. Used with permission.

Table 9.

Space Types	Relative Pressure(a)	Remarks
Offices - conference rooms	(+ +)	
Corridors	(+ +)	
Dry laboratories	(+)	
Laboratories with fumehoods	(+)	
High hazard (volatile hazard)	(- -)	Hazard concern is fire or explosion
Clean areas (b)	(+ + +)	
Pathogen-free areas (b)	(+ + +)	
Animal rooms	0	
Biohazard rooms	(-)	Hazard concern is Biological

a - Outdoor ambient is -0-
b - No particle rating

Adapted from *Designing A Laboratory.* Copyright 1989 by the American Public Health Association. Used with permission.

6.5.1 Supplemental (Spot) Cooling

There are several different types of spot cooling devices available that range from relatively inexpensive to expensive. If supplemental cooling is required (for instance, in a computer room), factor its specifications into any ventilation calculations. Remember that the cooling unit itself will generate heat, take up valuable space, and be expensive to run. Air-cooled units generate the most heat, but water-cooled units are illegal in some jurisdictions. For those units that produce condensate on the cooling coils, one might place "electric heat tape" on the bottom of the drip pans to speed the evaporation of standing water. Spot cooling can be effective in newly expanded areas where the air-handling or exhaust system is unable to move air efficiently, in a computer room where specialized "extra" cooling is necessary, or as a temporary measure while awaiting construction of a laboratory addition.

6.6 Code and Safety Issues

When designing a laboratory, appropriate engineering controls should be used.[ee] The use of personal protective equipment (PPE) should be

[e] In the U.S., appropriate engineering controls are required by OSHA.

the last line of defense in protecting employees from hazards. Examples of engi-neering controls include using sufficient air exchanges (at least 12 per hour) to keep air pure and using spot hoods to remove vapors that are heavier than air from the pathology/ histology laboratory. Other examples could include using fume hoods and building shields into the work area, rather than relying on goggles or face shields to protect the laboratorian from aerosols.

The most common reason that formalin vapors exceed specified tolerances in pathology laboratories is due to the practice of "pouring off" formalin from specimen containers before disposal. A low-lying vent close to or built into the disposal sink rectifies this problem.

When designing a laboratory, consider the maintenance workers who must perform their duties on the roof where air intake louvers and exhaust vents are located. Take care to design the placement of vents so that worker exposure to the material emitted from the vents is minimized.

The primary safety concern is keeping adequate levels of high-quality fresh air available, as well as removing fumes and heat from the laboratory. Additionally, temperature and humidity levels should be maintained at levels reasonable for both the comfort of the personnel and the optimal performance of equipment, test procedures, and other processes or products. Confine and eliminate toxic or hazardous vapors and noxious odors in a manner that ensures that personnel have minimal-to-no contact with them. Remove the aerosols of biohazardous materials so that personnel have no contact with them. Filter out respirable elements before air is dispersed within a laboratory area.

In the U.S., the National Fire Protection Association (NFPA) and various national, state, and local building codes provide the fundamental precautions for laboratory ventilation. The following NFPA standards[f] apply to laboratory ventilation:

- *NFPA 90A, Standard for the Installation of Air Conditioning and Ventilating Systems, 1996 edition.*
- *NFPA 90B, Standard for the Installation of Warm Air Heating and Air Conditioning Systems, 1996 edition.*
- *NFPA 30, Flammable and Combustible Liquids Code, 1996 edition.*
- *NFPA 45, Fire Protection for Laboratories using Chemicals, 1996 edition.*

These other authorities address laboratory ventilation:

- *OSHA Safety and Health Standards for General Industry. Available from the Occupational Safety and Health Administration, U. S. Department of Labor, U. S. Government Printing Office, Washington DC, 20402. Published in the Federal Register, 29CFR1910, December 6, 1991.*
- *State and local building codes (usually based on one of the national codes).*
- *Biosafety in Microbiological and Biomedical Laboratories, HHS Publication No. (CDC) 93-8395, 1993. Available from the U.S. Government Printing Office, Washington, DC.*
- *Heating, Ventilating, and Air Conditioning Systems, 1995. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1791 Tullis N.E., Atlanta, GA 30329.)*
- *Heating, Ventilating, and Air Conditioning Applications, 1996. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1781 Tullis N.E., Atlanta, GA.*

6.7 Ventilation Fundamentals

When designing the ventilation for a laboratory, keep the following points in mind:

- Factor in all equipment performance criteria, including heat exhaust and operating tolerances.
- There should be a minimum of 12 to 16 air exchanges per hour.
- There should be 100% fresh air intake and 100% exhaust to the outside for all technical work areas.
- Laboratory areas should be at a negative pressure relative to corridors. The rule-of-thumb is that air should move from clean to less clean areas.
- Air from laboratories must not be recirculated within a facility.
- There should be a thermostat control for each laboratory area.
- Design in engineering controls rather than relying on personal protective equipment to protect workers.
- Use spot hoods for exhausting large concentrations of heavier-than-air vapors.

[f] Available from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

- Have explosion-proof exhaust fans if volatile substances are exhausted.

- Shared air-handling systems should always be set for the area that requires the most cooling; use booster coils to increase heat to other areas.

- Supply air should be filtered only for dust. (The design characteristics of filtering systems and filter beds should be defined according to clinical needs.)

- The air-handling system should permit supplemental cooling (e.g., fan coil units) where heat load is high.

- Allow for growth of exhaust requirements (15-25%) for air-handling systems and accompanying duct work in the original design for ventilation.

6.8 Calculations

The calculations used by mechanical engineers and industrial hygienists to size the air handling system for the needs of the laboratory are complicated and take into account many factors. While laboratorians would not produce the final calculations, the following are some "rules of thumb" that may be used when estimating the size of the ventilation equipment needed for a laboratory.

Generally, three exhaust calculations are made, the largest of which determines the exhaust requirements.

The calculation examples below takes into consideration the following:

- The laboratory dimensions are: 30 ft (9.1 m) wide x 60 ft (18.3 m) long x 10 ft (3.0 m) high.

- The laboratory contain one fume hood and two biosafety cabinets for which the CFM requirements are:
  —Fume hood = 1,000 cfm (0.47 cms)[g]
  —Biosafety cabinet = 100 cfm (0.047 cms)

- The number of air exchanges per hour is 12.

Each calculation views the air handling requirements from one of three perspectives:

- The size of the area;

- The equipment containing exhaust devices, and

- The total heat loads (in British Thermal Units) generated by the following:

  —The quantity and type of laboratory equipment,
  —The number of personnel working in the area,
  —The quantity and type of light fixtures,
  —The amount of heat transferred through the exterior walls and windows, etc.

Calculation Example 1: For Size of the Area

$$\text{cfm (cms)} = \frac{\text{(Air exchanges/hour} \cdot \text{Room volume)}}{60}$$

$$= \frac{12 \cdot 30 \cdot 60 \cdot 10}{60}$$

$$= \frac{216{,}000}{60}$$

$$= 3{,}600\ (1.7).$$

for the size of the area, therefore, 3,600 cfm (1.7 cms) are needed for air handling.

Calculation Example 2: For Equipment Containing Exhaust Devices

cfm/min = Number of devices = cfm (cms) requirements.

= 1 fume hood[h] = 1,000 cfm (0.47 cms)

= 2 biosafety cabinets = 100 cfm (0.047 cms)

= 1,000 + 200

= 1,200 (0.52).

For equipment containing exhaust devices, therefore, 1,200 cfm/min (0.52 cms/min) are needed for air handling.

[g] Note: Fume hood exhaust air volume is also based on lineal feet of sash opening and the opening height. This information should also be taken into account when using this calculation.

[h] Note: Fume hood exhaust air volume is also based on lineal feet of sash opening and the opening height. This information should also be taken into account when using this calculation.

Calculation Example 3: Total Heat Loads Generated

Note: This is a complicated calculation based, among other things, on the desired air exchanges, the amount of heat generated in the area, and the amount transferred out. Because the mechanical engineer or industrial hygienist calculates the exact amount based on the individual laboratory characteristics, the formula will not be reproduced here.

A "rough" calculation based on 12 air exchanges per hour, can be estimated to be 1,825 cfm (0.86 cms), to properly remove total calculated heat load from the average laboratory.

Summary of Calculations

1. Area: 3,600 cfm/min (1.7 cms/min)
2. Exhaust devices: 1,200 cfm (0.52 cms)
3. Heat load: 1,825 cfm (1.7 cms)

Because the largest calculation results determine the exhaust requirements, in the above example, the supply and exhaust fans must be sized to handle 3,600 cfm (1.7 cms).

Besides identifying the appropriate size, the effectiveness of any air-handling system depends on a consistent program of overall preventive maintenance, inspection, and periodic testing of all parts of the system.

6.9 Minimum and Recommended Criteria

Table 10 shows the minimum and recommended criteria for laboratory ventilation:

Table 10. Criteria for Laboratory Ventilation

	Minimum	Recommended
Temperature variation	+/- 10 °C	+/- 5 °C
Humidity variation	30-70%	35-55%
Air exchanges	6	12-16
Fume hood face velocity*	60 (0.31)	100 (0.51)
Class I and IIA BSC inward airflow*	75 (0.38)	100 (0.51)
Class IIB BSC inward airflow*	85 (0.43)	100 (0.51)
Biological safety cabinets	†	‡
Expandability of ventilation design	10%	15-25%

* In linear feet per minute (meters per second)

† Required when concentrating specimens for mycobacteriology cultures and for fungal cultures other than yeasts and saprophytes.

‡ Recommended for all culture and cytology specimen set-up and processing.

7 Lighting

The following glossary is included for the convenience of those readers who are unfamiliar with lighting terminology. Readers are encouraged to review this glossary before delving into the main text of this section.

7.1 Glossary of Lighting Terminology[22]

Accent lighting, *n* - Directional lighting used to emphasize a particular object or draw attention to a part of the field of view. See "directional lighting."

Ambient lighting, *n* - Lighting throughout an area that produces general illumination.

Average luminance (of a surface), *n* - The average luminance (average photometric brightness) of a surface may be expressed in terms of the total luminous flux (lumens) actually leaving the surface per unit area. Average luminance specified in this way is identical in magnitude to "luminous existence," which is the preferred term.

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Biological safety cabinets	†	‡
Expandability of ventilation design	10%	15-25%

* In linear feet per minute (meters per second)

† Required when concentrating specimens for mycobacteriology cultures and for fungal cultures other than yeasts and saprophytes.

‡ Recommended for all culture and cytology specimen set-up and processing.

Average luminance (of a luminary), *n* - The luminous intensity at a given angle divided by the projected area of the luminary at that angle.

Baffle, *n* - A single opaque or translucent element used to shield a source from direct view at certain angles, or to absorb unwanted light.

Ballast, *n* - A device used with an electric-discharge lamp to obtain the necessary circuit conditions (voltage, current, and wave form) for starting and operating.

Brightness, *n* - See "subjective brightness," "luminance," and "veiling luminance."

Bulb, *n* - The glass enclosure of an incan-descent filament lamp.

Ceiling area lighting, *n* - A general lighting system in which the entire ceiling is, in effect, one large luminary. **NOTE:** Ceiling area lighting includes "luminous ceilings" and "lowered ceilings."

Color rendering, *n* - A general expression for the effect of a light source on the color appearance of objects in conscious or subconscious comparison to their color appear-ance under a reference light source.

Contrast, *n* - See "luminance contrast."

Contrast rendition factor, CRF, *n* - The ratio of visual task contrast with a given lighting environment to the contrast with sphere illumination.

Cut-off angle (of a luminary), *n* - The angle, measured up from nadir, between the vertical axis and the first line of sight at which the bare source is not visible.

Diffused lighting, *n* - Light that is not predominantly incident from any particular direction.

Direct glare, *n* - Glare resulting from high-luminance or insufficiently shielded light sources in the field of view or from reflecting areas of high luminance. It is usually associated with a bright area, such as with luminaries, ceilings, and windows that are outside the visual task or region being viewed.

Direct lighting, *n* - Lighting by luminaries distributing 90 to 100% of the emitted light in the general direction of the surface to be illuminated. The term usually refers to light emitted in a downward direction.

Directional lighting, *n* - Illumination on the work-plane or on an object that is predom-inantly from a single direction. See "accent lighting."

Disability glare, *n* - Glare that results in reduced visual performance and visibility. It is often accompanied by discomfort. See "veiling luminance."

Discomfort glare, *n* - Glare that produces discomfort. It does not necessarily interfere with visual performance or visibility.

Downlight, *n* - A small direct lighting unit that directs the light downward and can be recessed, surface mounted, or suspended.

Efficacy, *n* - See "luminous efficacy of a source of light."

Fenestration, *n* - Any opening or arrangement of openings (normally filled with media for control) for the admission of daylight.

Fixture, *n* - See "luminary."

Fluorescent lamp, *n* - A low-pressure mercury electric-discharge lamp in which a fluorescent coating (phosphor) transforms some of the ultraviolet energy generated by the discharge into light.

Foot candle, fc, *n* - The unit of illuminance when the foot is taken as the unit of length. It is the illuminance on a surface one square foot in area on which there is a uniformly distributed flux of one lumen.

General lighting, *n* - Lighting designed to provide a substantially uniform level of illuminance throughout an area, exclusive of any provision for special local requirements.

Glare, *n* - The sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted. It causes annoyance, discomfort, or loss in visual performance and visibility. See "direct glare," "disability glare," "discomfort glare," and "reflected glare."

High-intensity discharge lamps, *n* - A general group of lamps consisting of mercury, metal halide, and high-pressure sodium lamps.

Illuminance (lux or foot candle) meter, *n* - An instrument for measuring illuminance on a plane. Instruments that accurately respond to more than one spectral distribution are color corrected, i.e., the spectral response is balanced to V(λ) or V'(λ). Instruments that accurately respond to more than one spatial distribution of incident flux are cosine-corrected, i.e., the response to a source of unit luminous intensity, illuminating the detector from a fixed distance and from different directions decreases as the cosine of the angle between the incident direction and the normal to the detector surface. The instrument is composed of some form of photodetector, with or without a filter, that drives a digital or analog readout through appropriate circuitry.

Illumination, *n* - The act of illuminating or state of being illuminated. This term is sometimes used to describe the density of luminous flux on a surface (illuminance); however, usage in this sense is deprecated.

Incandescent filament lamp, *n* - A lamp in which light is produced by a filament heated to incandescence by an electric current.

Indirect lighting, *n* - Lighting by luminaries that distribute 90 to 100% of the emitted light upward.

Intensity, *n* - A shortened form of the terms "luminous intensity" and "radiant intensity." Often misused for "illuminance."

Lamp, *n* - A generic term for a synthetic source of light. By extension, the term is also used to denote sources that radiate in regions of the spectrum adjacent to the visible. **NOTE:** a lighting unit consisting of a lamp with shade, reflector, enclosing globe, housing, or other accessories is also called a "lamp." In such cases, to distinguish between the assembled unit and the light source within it, the latter is often called a "bulb" or "tube," if it is electrically powered. See also "luminary."

Lamp lumen depreciation factor, LLD, *n* - The multiplier to be used in illumination calculations to relate the initial rated output of light sources to the anticipated minimum rated output based on the relamping program to be used.

Level *of illumination*, *n* - See "illumination."

Light, *n* - Radiant energy that is capable of exciting the retina and producing a visual sensation. The visible portion of the electro-magnetic spectrum extends from about 380 to 770 nm.

Light loss factor, LLF, *n* - A factor used in calculating illuminance after a given period of time and under given conditions. It takes into account temperature and depreciation, maintenance procedures, and atmospheric conditions. Formerly called "maintenance factor."

Local lighting, *n* - Lighting designed to provide illumination over a relatively small area or confined space without providing any significant general surrounding lighting.

Localized general lighting, *n* - Lighting that uses luminaries above the visual task and also contributes to the illumination of the surround.

Lumens, lm, *n* - The unit of luminous flux.

Luminance (photometric brightness), *n* - The luminous intensity of any surface in a given direction per unit area of that surface as viewed from that direction. All things that are visible have some luminance. Units are candela per square meter [in Système International d'Unités (SI units)] or candela per square foot.

n - The relationship between the luminance of an object and its immediate background.

Luminance difference, *n* - The difference in luminance between two areas. It is usually applied to contiguous areas, such as the detail of a visual task and its immediate background, in which case it is quantitatively equal to the numerator in the formula for luminance contrast.

Luminance ratio, *n* - The ratio between the luminance of any two areas in the visual field.

Luminance threshold, *n* - The minimum perceptible difference in luminance for a given state of adaptation of the eye.

Luminary, *n* - A complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamps to the power supply.

Luminary dirt depreciation factor LDD, *n* - The multiplier to be used in illuminance calculations to relate the initial illuminance provided by clean, new luminaries to the reduced illumi-nation that they will provide due to dirt collection on the luminaries at the time at which it is anticipated that cleaning procedures will be instituted.

Luminous ceiling, *n* - A ceiling area lighting system comprising a contiguous surface of transmitting material of a diffusing or light-controlling character with light sources mounted above it.

Luminous efficacy of a source of light, *n* - The quotient of the total luminous flux emitted by the total lamp power input. It is expressed in lumens per watt.

Lux, lx, *n* - The unit of illuminance as expressed in SI units. It is the illumination on a surface one square meter in area on which there is a uniformly distributed flux of one lumen, or the illumination produced at a surface all points of that are at a distance of one meter from a uniform point source of one candela.

Maintenance factor, MF, *n* - A factor formerly used to denote the ratio of the illuminance on a given area after a period of time to the initial illuminance on the same area. See "light loss factor."

Matte surface, *n* - One from which the reflection is predominantly diffuse, with or without a negligible specular component.

Peripheral vision, *n* - The seeing of objects displaced from the primary line of sight and outside the central visual field.

Point of fixation, *n* - A point or object in the visual field at which the eyes look and upon which they are focused.

Portable lighting, *n* - Lighting by means of equipment designed for manual portability.

Portable luminary, *n* - A lighting unit that is not permanently fixed in place.

Quality of lighting, *n* - Pertains to the distribution of luminance within a visual environment. The term is used in a positive sense and implies that all luminance contributes favorably to visual performance, visual comfort, ease of seeing, safety, and aesthetics for the specific visual tasks involved.

Reflected glare, *n* - Glare resulting from specular reflections of high luminance in polished or glossy surfaces in the field of view. It usually is associated with reflections from within a visual task or areas in close proximity to the region being viewed. See "veiling reflection."

Reflection, *n* - A general term for the process by which the incident flux leaves a surface or medium from the incident side.

Reflector, *n* - A device used to redirect the luminous flux from a source by the process of reflection.

Refraction, *n* - The process by which the direction of a ray of light changes as it passes obliquely from one medium to another in which its speed is different.

Regular (specular) reflection, *n* - That process by which incident flux is reindirected at the specular angle.

Shielding angle (of a luminary), *n* - The angle between a horizontal line through the light center and the line of sight at which the bare source first becomes visible. See "cut-off angle (of a luminary)."

Specular surface, *n* - One from which the reflection is predominantly regular. See "regular (specular) reflection."

Stray light, *n* - Light from a source that is scattered onto parts of the retina lying outside the retinal image of the source.

Subjective brightness, *n* - The subjective attribute of any light sensation giving rise to the percept of luminous intensity, including the whole scale of qualities of being bright, light, brilliant, dim, or dark.

Supplementary lighting, *n* - Lighting used to provide an additional quantity and quality of illumination that cannot readily be obtained by a general lighting system and that supplements the general lighting level, usually for specific work requirements.

Surface-mounted luminary, *n* - A luminary mounted directly on the ceiling.

Suspended (pendant) luminary, *n* - A luminary hung from a ceiling by supports.

Task lighting, *n* - Lighting directed toward a specific surface or area that provides illumination for visual tasks.

Tube, *n* - See "lamp."

Tungsten-halogen lamp, *n* - A gas-filled tungsten-incandescent lamp containing a certain proportion of halogens. **NOTE:** The tungsten-iodine lamp (UK) and quartz-iodine lamp (USA) belong to this category.

Veiling luminance, *n* - A luminance superimposed on the retinal image that reduces its contrast. It is this veiling effect produced by bright sources or areas in the visual field that results in decreased visual performance and visibility.

Veiling reflection, *n* - Regular reflections superimposed on diffuse reflections from an object that partially or totally obscures the details to be seen by reducing the contrast. This is sometimes called "reflected glare."

Visibility, *n* - The quality or state of being perceivable by the eye. In many outdoor applications, visibility is defined in terms of the distance at which an object can just be perceived by the eye. In indoor applications, it is usually defined in terms of the contrast or size of a standard test object, observed under standardized view-conditions, having the same threshold as the given object.

Visual acuity, *n* - A measure of the ability to distinguish fine details. Quantitatively, it is the reciprocal of the angular size in minutes of the critical detail that is just large enough to be seen.

Visual angle, *n* - The stretched angle; the angle determined by an object or detail from the point of observation. It is usually measured in minutes of arc.

Visual field, *n* - The focus of objects or points in space that can be perceived when the head and eyes are kept fixed. The field may be monocular or binocular.

Visual perception, *n* - The interpretation of impressions transmitted from the retina to the brain in terms of information about a physical world displayed before the eye.

Visual performance, *n* - The quantitative assessment of the performance of a task taking into consideration speed and accuracy.

Visual surround, *n* - Includes all portions of the visual field except the visual task.

Visual task, *n* - Conventionally designates those details and objects that must be seen for the performance of a given activity and includes the immediate background of the details or objects.

Work-plane, *n* - The plane at which work usually is done and at which the illuminance is specified and measured. Unless otherwise indicated, this is assumed to be a horizontal plane 0.76 cm (30 in) above the floor.

7.2 Design and Configuration of Lighting Systems

The clinical laboratory is not a static environment; its design and configuration change continually. These changes are precipitated by new instrumentation, computerization, and automation. As clinical procedures

become more complicated and sophisticated, they require various types of light.

One major contribution to a better work environment is a well-designed lighting system that provides various levels of illumination. The overall look of the work environment in laboratories has changed from a white or pea-green institutional look to a softer, less stressful one. Available levels of illumination range from the dramatic (e.g., in waiting rooms, donor rooms, and lounges) to the color-corrected (e.g., in areas used for tissue-cutting, staining, and growth determinations on microbiological media). High-level illumination is required in grossing and frozen-section laboratories, as well as in the morgue/autopsy area.

This section addresses changes in the clinical laboratory environment by relating them to specific recommendations and standards. Energy conservation and operating cost containment, for example, are subjects that are discussed daily. It is therefore imperative that we learn to design laboratories with more efficient lighting.

7.3 Quantity

7.3.1 Illumination

The amount of illumination needed is determined by the type of task to be performed, the color of the work surface, the color of the adjacent walls and the ceiling, the distance from the lighting fixture to the work surface, and the spacing of the light fixtures.

Once these details are addressed and criteria are determined, an appropriate lighting fixture can be selected, which will establish the spacing and the number of fixtures required to illuminate a specific area.

7.3.2 Location of Luminaries

To achieve uniform distribution of illumination and to eliminate shadows, mount the luminaries perpendicular or diagonal to the work surface (see Figures 17 and 18). Luminaries that are mounted parallel to the work surface usually create a shadow, either from the person working at the bench or from overhead cabinets. If there are no cabinets above the work surface, luminaries may be located parallel to and directly over the active edge of the work surface (see Figure 19).

Note that dark or off-white matte finish work surfaces reduce the amount of reflection and glare; thus, eye fatigue and eye strain are reduced as well.

7.4 Quality: Identifying Types of Luminaries

Many types of luminaries are currently available, and new types are developed almost daily. The following sections identify the more common luminaries and their individual characteristics.

7.4.1 Incandescent Filament Lighting

The advantages of incandescent filament lighting are evident in its low initial cost, good color-rendering properties, and good optical control capabilities. Its disadvantages are shorter lamp life, excess heat, and lower lu-mens per watt. Incandescent lighting includes the tungsten-halogen lamp, which has better light output, longer lamp life, and can be smaller in size.

7.4.2 Fluorescent Lighting

Fluorescent lighting provides a higher lumens output per watt, longer lamp life, low brightness, and a good range of color rendition. Usually, the initial cost for fluorescent lighting is higher than for incandescent filament fixtures, but the operating cost is less expensive. Fluorescent lamps are available in straight linear, U-shaped, and circular tubes. Because the U-shaped tube is not easy to replace and maintain, the maintenance departments within many facilities do not use it.

There are a variety of different diffusers, prismatic lenses, parabolic reflectors, protective dust covers, and water-tight covers available for specialty areas. Note, it is not necessarily the number of foot candles available but the quality and uniformity of the available light that make a difference.

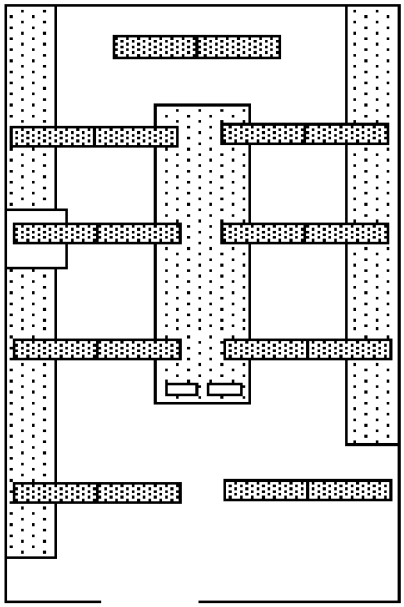

Figure 17. Location of luminaries perpendicular to the work surface.

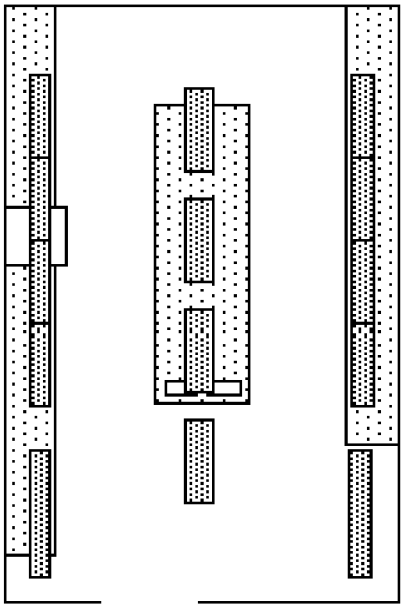

Figure 18. Location of luminaries parallel to the work surface.

Fluorescent lights are available in many different "color temperatures" and are the preferred method of illuminating indoor work environments. Color temperature is measured in kelvins (K) (range: 9,000K to 1,500K; 9,000 to 1500 °C). Higher temperatures of 4,000K (4,000 °C) or more fall within the cool (blue) range and temperatures of 3,100K (3,000 °C) or less fall within the warm range (orange-red).

7.4.3 High-Intensity Discharge (HID) Lighting

High-intensity density lamps include mercury, metal halide, and high-pressure sodium. All of these lamps have a long life and high lumens per watt compared to incandescent filament lamps. One disadvantage is the slow light output when energized. For this reason, it is recommended that they be augmented with fluorescent or incandescent lighting systems when used as part of the emergency lighting system. The physical appearance of two luminaries may be almost identical, but they can vary in lighting quality and performance. Therefore, it is recommended that performance charts[22] be consulted for comparison of the output of each luminary using distribution curves and photometric testing data (Table 11).

Many different types of fixtures exist that can be used exclusively or in combination to get the desired illumination. Examples include fully recessed, semirecessed, suspended or pendant, valance, sconce, and track lighting, to name a few. Each has different lighting distributions, as s hown in Figure 19. A combination of theseixtures with accent, spot, highlight, and task illumination can make a major contribution to the comfort level, aesthetics, and visual appeal of an otherwise ordinary work space.

7.4.4 Video Display Terminals (VDTs)

The screens of video display terminals present special problems for their users: reflective glare and adaptation to brightness. Because the use of VDTs with the laboratory and hospital information systems (LIS and HIS) has become so prevalent and VDTs are also becoming a major part of the automated instrumentation in use today, it is important to understand these special problems

There are a number of solutions available, such as using indirect overhead light fixtures (see Figure 19) that can correct reflective glare and facilitate adaptation to brightness. Although

using indirect overhead light fixtures helps correct these problems, it requires a finished ceiling with enough distance between the lighting fixture and the ceiling (18 inches; 45.7 cm) so that it can reflect the light efficiently. With the increased ceiling height, this could necessitate adding cubic space to the building, which would require an increase in the heating and cooling. This could possibly increase the size of the exterior walls, increase the length of the columns, and increase the size of the footings, which might contribute to increasing the initial and operating costs of the facility. Thus, the best lighting characteristics for a VDT area are a combination of downlighting luminaries that have the same luminance as the ceiling and indirect fixtures that provide a uniform ceiling brightness (see Figure 19). To address the problem of reflective glare, parabolic reflectors also can be used in the luminaries.

7.4.5 Specialty Lighting[23,24]

Areas used for viral isolation should protect the staff and the specimens from contamination. Ultraviolet (UV) light sources are recommended for sterilization. The fixtures should be mounted at a minimum of seven (7) feet from the finished floor to the bottom of the fixture. The number of fixtures required can be determined by your electrical engineer.

When using UV lighting, one must be careful to verify that the finishes (wall coverings paints, countertops, etc.) can withstand the bleaching effect of UV light.

Table 11. Lighting Design Considerations

CRITERIA	BLOOD BANK	HISTOLOGY	CYTOLOGY	MICROSCOPIC VIEWING	GROSSING	FROZEN SECTION	CHEMISTRY	MICROBIOLOGY	HEMATOLOGY	MORGUE/AUTOPSY	REMARKS
1. Color rendering		X	X		X	X		X		X	Tissue and media viewing.
2. Donor comfort	X										Patient comfort, less stressful.
3. Oblique illumination	X										View veins, easier in oblique light.
4. Background											
a. Dark in color				X							Better contrast with low reflectance.
b. Low reflectance				X							Better contrast, reduced glare.
5. High illuminance						X		X			View tissue and in cavities.
6. Diffuse lighting						X					Better to view inside of cryostat.
7. Task lighting	X						X	X	X	X	Useful when drawing patients and viewing plates. Locate under cabinets.

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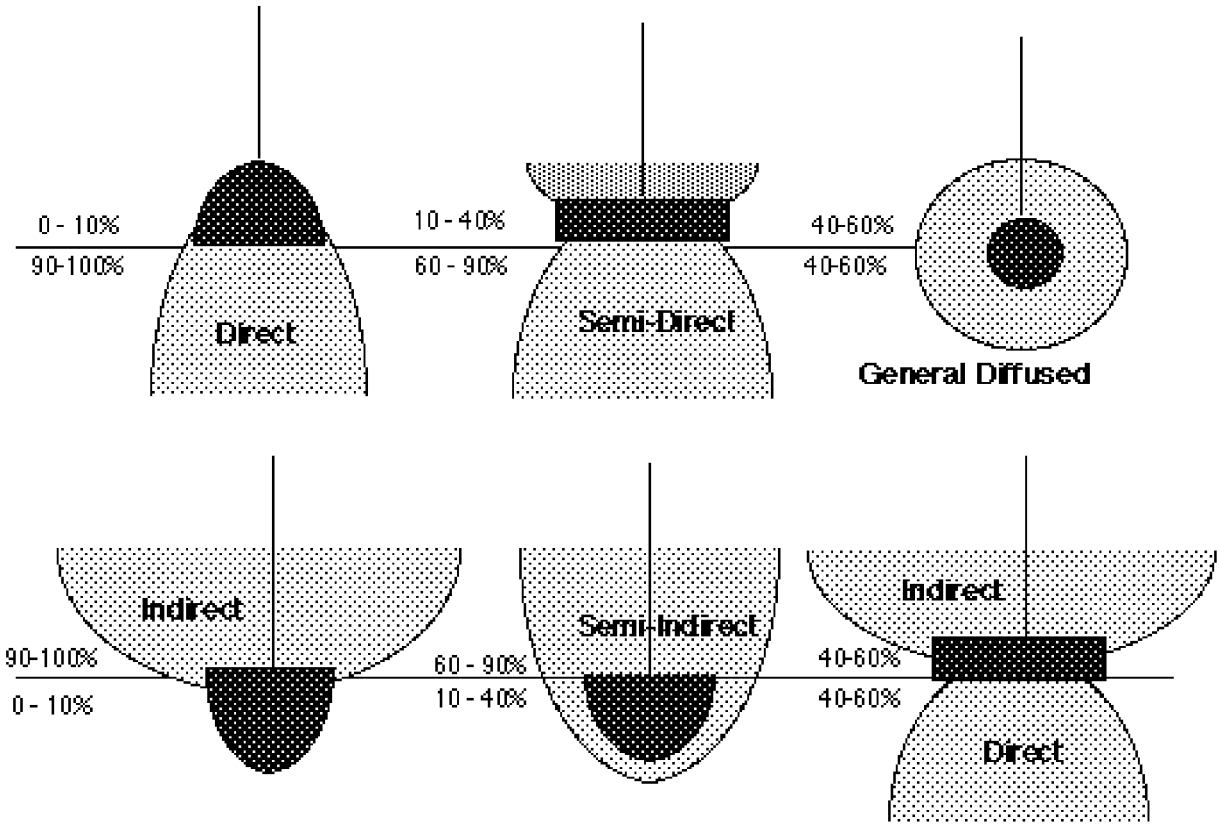

Figure 19. Light distribution.

7.5 Controls

Controls for switching the lights on and off should be located at entrances and exits to each space. Fluorescent luminaries should be double switched so that, depending on the level of illumination desired, half of the tubes may be switched on at a time.

The invention of the electronic ballast allowed the dimming of fluorescent lights to be done more efficiently and it eliminated the usual "flickering" present at lower illumination levels. The electronic dimmer switch not only gives better lighting regulation, but it is also more energy efficient than regular dimmer switches. Furthermore, the electronic dimmer switch completely eliminates any flickering of the lights and hum of the ballast.

An alternate method of light control is to install both incandescent and fluorescent lights in the same area, and then switch off the fluorescent lights and dim the incandescent lights with an inexpensive conventional dimmer.

7.6 Expandability

The most successful method of providing for expansion or increased use of a specific area is to design a good uniform illumination system from the start. This allows for reconfiguration of the area but precludes having to pay a premium or being inconvenienced with costly shutdowns. The illumination levels can be occasionally augmented, without requiring additional overhead luminaries, by introducing additional task lighting at the work surface.

If the future functions of a specific area are known, empty conduits can be installed where additional luminaries might be required. When it becomes necessary to add luminaries, additional wires can be pulled into the empty conduit to accommodate the new luminaries. By wiring the original luminaries with flexible "pig tails" (where permitted by code) and using a lay-in ceiling, the spacing of existing luminaries can be easily modified at minimal cost.

To complete this process, it is necessary to provide additional capacity in the lighting panels to accommodate the increased electrical load. The load increase for each circuit can be calculated by the electrical engineer when the original calculations are made. Circuiting for the laboratory should be generous, with dedicated circuits for special instruments and equipment. A maximum of six outlets per circuit is recommended.

7.6.1 Emergency Lighting

Emergency lighting has traditionally been used to address (1) evacuation in case of emergency and (2) provision of life-support services to patients who are unable to be evacuated. Evacuation lighting is usually low illuminance that directs patients and staff to evacuation routes. Life-support light can be at a much higher luminance equal to regular lighting within the critical care area and the surgery suite.

To support the patient life-support service, the laboratory must retain quality general illumination for safety and high-quality illumination for the blood bank, "stat" instruments (e.g., chemical analyzers, hematology, and analyzers) and the frozen-section laboratory. The level of task lighting should be equal to the regular illumination.

If there is a major catastrophe (e.g., tornado, hurricane, or earthquake), the laboratory must remain operational as long as possible to support the critical care, surgery, and emer-gency departments. The emergency generator must have the electrical capacity to accomplish this.

7.7 Codes, Regulations, and Safety

The electrical engineer and the electrical contractor should check with the local governing authorities for any local modifications to the codes.

In the U.S., the following major codes and regulations are used when designing lighting systems:

NFPA-30, Flammable and Combustible Liquid Code, 1996 edition. Available from National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

NFPA-70, National Electrical Code, 1993 edition. Available from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

NFPA-90A, Installation of Air Conditioning and Ventilating Systems National Fire Codes, 1996 edition. Available from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

NFPA-90B, Warm Air Heating and Air Conditioning National Fire Codes, 1996 edition. Available from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

NFPA-99, Standard for Health Care Facilities, 1993 edition. Available from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

NFPA-101, Life Safety Code, 1991 edition. Available from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

Guidelines for Construction and Equipment of Hospital and Medical Facilities, 1993 edition. Available from the American Institute of Architects Press, 1735 New York Avenue, N.W., Washington, DC 20006.

Lighting for Health Care Facilities. Copyright 1985 by the Illuminating Engineering Society of North America, 345 East 47th Street, New York, NY 10017.

Electrical safety. In Hospital Electrical Compendium. Copyright 1984 by American Society for Hospital Engineering of the American Hospital Association, 840 North Lake Shore Drive, Chicago, IL 60611.

7.8 Fundamentals

Recommendations about illumination vary according to specific lighting needs. For specific guidance on some fundamentals of illumination, see the tables in Appendix A.

8 Fresh and Waste Water

Nearly all laboratories require a reliable supply of water. Even if water is carried into the laboratory as bottled water for special applications, rather than supplied through water lines, there is still the problem of where the waste water goes. One of the most complex components of a laboratory utility support system is the supplying of water of different purities and temperatures to widely separate locations. Another component is the removal of waste water from these separate locations. This section addresses some of the issues that affect the safety and functionality of potable, treated, and waste water systems in modern laboratories.

8.1 Quantity

Generally, laboratories are not large water users. While it is recommended that persons drink 8 oz (236.6 mL) of water for every 10 lbs (4.54 kg) of body weight, this recommendation would have a 150-lb (68 kg) person taking in 120 oz (3.6 L), or about 1 gal (128 oz; 3.9 L), of water

each day. Half that or less would typically be consumed from a potable water supply at work. However, that same person may flush four times that amount, or 2 gal (7.6 L), of potable water down the toilet during a shift. Emergency showers are infrequently used, but they could use 450 gal (170.6 L) during a 30-min wash-down period. The largest volume of treated or purified water is often used for washing glassware, which amounts to 10 to 20 gal (37.9 to 75.8 L) for an under-the-counter glassware washer to complete its washing process. To better understand its water-consumption needs, a laboratory should list the type and quantity of water used during a one-week or a one-month period.

8.2 Quality

Generally, references to water quality deal with issues of water purity. Water of the highest quality is therefore only water (H_2O), with everything else removed. Many, or even most, laboratory applications do not require water of the highest attainable purity. However, it is vitally important that water of the right purity be available where and when it is needed. Water used in laboratories is of two basic types: potable (drinkable) water, and treated (purified) water. (Refer to NCCLS document C3--*Preparation and Testing of Reagent Water in the Clinical Laboratory* for more detailed information.)

8.3 Control

One of the most important decisions influencing the overall scope of potable water utilization and attendant supply, and waste water removal plumbing is the number of sinks in the laboratory. For instance, if a laboratory has ten sinks measuring 2 x 1 ft (0.6 x 0.3 m) (L x W), with 1 ft (0.3 m) of clear work area dictated on each side, it has allocated about 40 sq ft (3.68 sq m) of laboratory floor space to sink-related functions. This would suggest that the number of sinks in the laboratory should be considered during the space-planning phase.

To protect the potable water system from contamination from waste or "purified" water systems, backflow-preventing valves must be installed. Vacuum breakers should be attached to potable or treated water faucets where appropriate to prevent cross-contamination at that point. Potable water for eye wash stations and emergency showers should have an appropriate temperature control and delivery rate. Water from emergency showers should have a pressure of 5 to 50 psi (0.35 to 3.5 kg per sq m), be no less than 72 to 74° ± 5°F (40 to 41° ± 3 °C), and have a flow rate of 30 to 60 gal per min (1.9 to 3.9 L per second) at the showerhead. Regulate eye wash station water at 60 to 95 °F (33 to 53 °C) at a pressure of 20 to 125 psi (1.4 to 8.9 kg per sq cm). Overhead fire-retardant sprinkler systems, emergency showers, and eye wash stations should have alarms that will alert others when one of these emergency, high-volume water discharge systems is activated.

8.4 Supply and Removal

Water may be supplied to nearly any location either by running from larger (e.g., 1-inch [2.54 cm]) lines in peripheral walls through chase systems into the laboratory area or dropped from larger lines running across the ceiling. Supply lines may be of copper or appropriate polyvinyl chloride, depending on the application and codes. If hot water of prescribed temperature is needed without a warm-up period to maintain specific temperatures, such as for eye washes and emergency showers, some type of constant circulation system is necessary. Generally, the temperature of domestic and most laboratory hot water is about 140 °F.

Because nearly all waste water lines rely on gravity to move the waste water through plumbing lines to a drain, waste water lines pose special problems. Laboratory waste lines should not use the same drain lines as sanitary waste. A separate drain line system permits special treatment or diversion of laboratory waste water before it enters the facility's general waste water system. Because laboratory staff members frequently discharge acids, alkali, or organic solvents into the drains, the drain pipes should be constructed of nonreac-tive materials, such as plastic or glass. This reduces the need for periodic surveys of laboratory users to be sure that they are not putting items down the drain that can damage the laboratory's plumbing.

Most locations use sink drain pipes of 3 inches (7.6 cm) or less in diameter that require a 1/4-inch (0.6 cm) drop per running foot of drain pipe. Because the lowest point of the drain pipe cannot be below the bottom of the trap under the sink, often 3 inches (7.6 cm) below the drain pipe takeoff point, the maximum length of the drain pipe is 12 ft (3.7 m), with a practical limit of 10 ft (3.0 m). A drain line that drops below the level of the trap would create a siphon and

empty the trap. One way to solve the drain line access problem is to put main drain lines along opposing perimeter walls. Then sinks and any drain-requiring activity can be added simply by tying into the main drain system in whichever perimeter wall is closest to the proposed sink location. This peripheral wall drain system is often used in open laboratory designs, which use "U"-shaped workcenters that extend like fingers into the room from perimeter walls.

So that purified water going to various points in the laboratory does not sit in the lines, water-treatment systems should be attached to a double-line recirculation system, as opposed to a single-line, dead-end system. Because the additives designed to keep such growth under control have been removed, bacterial contamination can occur quickly in purified water.

8.5 Expandability

If the suggestions in Section 5.4 are followed, expansion of either potable or purified water to additional locations does not involve anything more than running a line through a workstation chase to a peripheral wall feed line. Sink drains can be routed to peripheral wall drain systems in a similar manner. The location of drains can be one of the biggest limiting factors in laboratory design, making otherwise flexible laboratory designs revolve around drain locations.

By taking advantage of a few point-of-use devices, the addition of cold and hot water service, as well as waste water removal, can be accomplished in virtually any location. Here, only cold, potable, or purified water service is supplied to the sink location, usually from a ceiling-supplied water line. Hot water is instantly supplied on demand by a point-of-use heater, which is usually mounted inside the casework underneath the sink. Waste water is directed up to a waste water drain in the ceiling by a pump that is also located inside the casework underneath the sink. The whole sink station is sometimes made into a unit that can be moved to any location within the laboratory 0hat has the necessary overhead plumbing, and it can be operational in a few hours.

8.6 Code and Safety Issues

Some potable water systems require pumps to raise water pressure and move the water to where it is needed. If the seals become worn, these pumps can contaminate the water.

(For information in the U.S. on plumbing, see NFPA 56C, which was subsumed into NFPA-99, Standard for Health Care Facilities, 1993 edition. NFPA-99 is available from the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.)

8.7 Fundamentals

Potable water must be used in all hot and cold water lines connected to sinks, emergency and regular whole body showers, eyewash stations, and drinking fountains. Typically, potable cold water also supplies overhead fire sprinkler systems, chill water for air-conditioning systems, and special treatment systems that produce nonpotable water, such as that from deionized and distilled water systems.

Municipal potable water standards permit concentrations of dissolved particulate matter, gases, organic compounds, hardness (calcium and magnesium carbonate), salts (sodium), treatment agents (fluoride), and microorganisms that are not acceptable for even crude laboratory analyses. The amount of impurities that must be removed from the potable water before the water is usable depends on how the purified water is to be used. Water purification can be viewed as a continuum along which impurities from input potable water are progressively removed. One example of such a system employs a series of canisters whose contents perform the functions shown below (Box 1).

Step A	Step B	Step C	Step D
Filtration ---->	**Deionization ---->**	**Carbon Absorption ------>**	**Reverse Osmosis**
Suspended Agent Matter Removal	Ionized Salts Removal	Organic Material Removal	Pyrogens & A,B,C Removal

Box 1

Even though the water from the sequential treatment system illustrated above would have a high electrical resistance, which indicates removal of ions capable of conducting water from either step C or D remains one of the best methods to produce ultrapure sterile water that might be used for such applications as preparation of medicines for intravenous use. Most laboratory water usage for technical procedures is satisfied by steps A, B, and C, with a final 0.22 μm filtration to remove any bacterial contamination in the canisters.

8.8 Calculations

Use the following formula (Box 2) to calculate the square feet of laboratory occupied by sinks:

$$\frac{[(\text{Sink L" x W" }) + (\text{Needed Extra Counter Work Area L" x W" })]}{144}$$

Box 2

8.9 Minimum and Recommended Criteria

Table 12 shows the minimum and recommended criteria for system laboratory water.

Table 12. Criteria for System Laboratory Water

	Minimum	Notes
General hot water temperature	120 °F (67 °C)	140 °F (78 °C) is recommended
Plumbed and self-contained eyewash	0.4 gal/min (1.5 L/m)	A slow stream of water is best to prevent injury to the eye.
Eye/face wash and drench hoses	3.0 gal/min (11.4 L/min)	
Eyewash water temperature	60°F (33 °C)	70 °F (21°C) is recommended and 95 °F (34°C) is the highest
Emergency shower temperature	70 °F (21°C)	70-90 °F (21-50 °C) is recommended

Appendix A. Fundamentals of Illumination

Table A. Currently Recommended Illuminance Categories and Illuminance Ranges for Health Care Facilities (Target-Maintained Levels)

Type of Activity	Illuminance Category	Ranges of Illuminances Lux*	Foot candles†	Reference Work-Plane
Public spaces with dark surroundings	A	20-30-50	2-3-5	General lighting throughout spaces
Simple orientation for short, temporary visits	B	50-75-100	5-7.5-10	
Working spaces where visual tasks are only occasionally performed	C	100-150-200	10-15-20	
Performance of visual tasks of high contrast or large size	D	200-300-500	20-30-50	Illuminance on task
Performance of visual tasks of medium contrast or small size	E	500-750-1000	50-75-100	
Performance of visual tasks of low contrast or very small size	F	1000-1500-2000	100-150-200	
Performance of visual tasks of low contrast and very small size over a prolonged period	G	2000-3000-5000	200-300-500	Illuminance on task, obtained by a combination of general and local
		ary) lighting.	(supplement-	
Performance of very prolonged and exacting visual tasks	H	5000-7500-10000	500-750-1000	
Performance of very special visual tasks of extremely low contrast and small size	I	10000-15000-20000	1000-1500-2000	

Modified with permission from *Lighting for Health Care Facilities*. The Illuminating Engineering Society of North America, 120 Wall Street-Floor 17, New York, NY: 1985

* To convert Lux to Lumen per sq m, multiply by 1.

† To convert Footcandles to Lumen per sq m, multiply by 10.76.

Appendix A (Continued).

Table B. Currently Recommended Illuminance Categories for Health Care Facilities

Area Activity	Illuminance Category
Autopsy and morgue*†	
Autopsy, general	E
Autopsy table	G
Morgue, general	D
Corridors*	
Operating areas, delivery, recovery, and laboratory suites and service	E
Cystoscopy room*†	E
Examination and treatment rooms*	
General	D
Local	E
Local for reading	D

* Good to high color-rendering capability should be considered in these areas. As lamps of higher luminous efficacy and higher color-rendering capability become available and economically feasible, they should be applied in all areas of health care facilities.

† Variable (dimming or switching).

See Table A for illuminance ranges for the various illuminance categories.

Modified with permission from *Lighting for Health Care Facilities*. The Illuminating Engineering Society of North America, 120 Wall Street-Floor 17, New York, NY: 1985.

Appendix A (Continued).

Table B. (Continued)

Area Activity	Illuminance Category
Laboratories*	
Specimen collecting	E
Tissue laboratories	F
Microscopic reading room	D
Gross specimen review	F
Chemistry rooms	E
Bacteriology rooms	
General	E
Reading culture plates	F
Hematology	E
Lobby	C
Locker rooms	C
Stairways	C
Toilets	C
Utility room	D
Waiting areas*	
General	C
Local for reading	D

* Good to high color-rendering capability should be considered in these areas. As lamps of higher luminous efficacy and higher color-rendering capability become available and economically feasible, they should be applied in all areas of health care facilities.

† Variable (dimming or switching).

See Table A for illuminance ranges for the various illuminance categories.

Modified with permission from *Lighting for Health Care Facilities*. The Illuminating Engineering Society of North America, 120 Wall Street-Floor 17, New York, NY: 1985.

Appendix A (Continued).

Table C. Currently Recommended Illuminance (in Lux and Foot candles) on Tasks for Emergency or Continuity Service (for Use When Normal Service is Interrupted)*

	Lux†	Foot candles‡
Exit ways	30	3
Corridors leading to exits, at floor	30	3
Stairways leading to exits, at floor	30	3
Exit direction signs, face of sign	50	5
Exit doorway, at floor	30	3
Blood bank area	50	5
Hospital elevator-exit lighting	50	5
Stairwells	50	5

* These are the minimum lighting levels. It is particularly desirable to increase them to as near the levels that are normally provided in these areas as the available capacity of the emergency electrical supply will permit.

† To convert Lux to Lumen per sq m, multiply by 1.

‡ To convert Footcandles to Lumen per sq m, multiply by 10.76.

Modified with permission from *Lighting for Health Care Facilities*. The Illuminating Engineering Society of North America, 120 Wall Street-Floor 17, New York, NY: 1985.

Table D. Recommended Luminance Ratios*

To achieve a comfortable balance in health care facilities, it is desirable and practical to limit luminance ratios between areas of appreciable size from normal viewpoints as follows:

- 1 to 1/3 between task and adjacent surroundings (such as between a book and the tabletop).
- 1 to 1/5 between task and more remote darker surfaces (such as between a book and the floor).
- 1 to 5 between task and more remote lighter surfaces (such as between a book and the ceiling).

* These ratios are recommended as maximums; reductions are generally beneficial. Modified with permission from *Lighting for Health Care Facilities*. The Illuminating Engineering Society of North America, 120 Wall Street-Floor 17, New York, NY: 1985.

Appendix A (Continued).

Table E. Recommended Surface Reflectance (Also, see specific areas in Section 4.)

Surface	Reflectance Equivalent Range (%)
Ceiling finishes[a]	80-90
Walls	40-60
Furniture	25-45
Equipment	25-45
Floors	20-40

[a] Recommended reflectances are for finish only. Overall average reflectance of acoustic materials may be somewhat lower.

Modified with permission from *Lighting for Health Care Facilities*. The Illuminating Engineering Society of North America, 120 Wall Street-Floor 17, New York, NY: 1985.

Table F. General Conversion Formulas for Power and Lighting Applications

W = VA	W = Watts
A = W/V	A = Amps
V = W/A	V = Volts

Lux · 0.0929 = foot candles.
Lumens/sq ft · 1.0 = foot candles.
Lumen · 1.076 = W.
Lumen · 10.76 = lumen/m^2
Foot candle · 10.764 = lumen/m^2

Modified with permission from *Lighting for Health Care Facilities*. The Illuminating Engineering Society of North America, 120 Wall Street-Floor 17, New York, NY: 1985.

Appendix B. Biosafety Levels

Level 0: Where handling materials and performing tasks does not involve contact with nor exposure to blood, body fluids, body secretions, or tissue.

Level 1: Where closed biological specimens as noted in Level 0 are handled, as with the receiving area in a laboratory.

Level 2: This is the level typically associated with clinical laboratory testing where there can be direct exposure to blood, body secretions, body fluids, or tissue. The risk to life due to inhalation or aerosol exposure is low.

Level 3: Where work is done using agents that cause lethal or serious disease through inhalation.

Level 4: Where agents pose a high risk to life through aerosols.

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Summary of Comments and Subcommittee Responses

GP18-P: Laboratory Design; Proposed Guideline

General

1. There is too much emphasis on materials management techniques and forecasting storage needs. Most of this information is more applicable in a document on inventory control.

- **The subcommittee believes the information on materials management does not detract from the document and may be beneficial to the user.**

2. The document should discuss power requirements that are specific to a laboratory, i.e., uninterruptible power supply and dedicated circuits.

- **The subcommittee added a new Section 4.7.3 that addresses electrical power.**

3. Information on planning for an autoclave with its exhaust requirements should be added to the guideline.

- **The following sentence has been added to Section 6.2, *Backdraft, slot, or spot hoods*: "The planner should provide adequate service access per the manufacturer's recommendations."**

4. The figures at the end of the document are helpful, but they would be more useful if they were incorporated into the document. Presently, they are tacked on at the end like an afterthought.

- **The subcommittee agrees with the comment and the figures have been incorporated into the text of the document.**

5. GP18 was written to provide general guidelines for design of any laboratory. Many laboratory areas, including molecular pathology PCR laboratories, have specific design requirements and inclusion of these would best be done by making this a two volume set. One set for general criteria and the second for specific guidelines.

- **The subcommittee agrees that GP18 is a general laboratory design aid. To clarify this, the following two sentences have been added to the end of Section 2, Scope: "This document is intended to give general guidance in laboratory design for those working in and managing laboratories. Many specific issues and important considerations that will need to be considered in well designed laboratory are beyond the scope of this guideline and are best worked through with the project's architect." The recommendation for a companion guideline that considers specific laboratory design requirements has been forwarded to the Area Committee on General Laboratory Practices for consideration.**

6. GP18-P potentially would be useful for laboratory management involved in design, planning, or negotiating for new space. My principal concern is that this document will become more than just a guideline and will become a requirement for CAP accreditation, not unlike GP2 (Procedure Manuals), that is more restrictive than helpful.

- **The subcommittee understands the commenter,s concern; however, this issue is not one the subcommittee can address. An "NCCLS guideline" is a document developed through the consensus process describing criteria for a general operating practice, method, or material for voluntary use. A guideline can be used as written or modified by the user to fit specific needs. NCCLS standards and guidelines are not intended to take the place of statutes or regulations.**

7. I am particularly concerned with some of the naive assertions made, such as in section 3.1.1, "Overcrowding in the clinical laboratory is due to conscious decisions made by laboratory leaders

who decide to do more work without getting more space for administration before proceeding." I assume the authors would also characterize submission to oppression as a conscious decision. I do not know and cannot tell what they meant to imply by this and other statements of like kind. They are not constructive, and I think they set an arrogant and wrong tone to the document. By and large, laboratory leadership has allowed physical conditions to be less than desirable, and sometimes less than acceptable, because there was no other choice. The responsibility, which is implied by "conscious decision," for the poor conditions, however, lies with hospital or medical center administration. The document should stick to the facts of the laboratory design and provide a useful reference for design standards such as airflows, bench space, drench showers and other safety provisions, hoods, storage space, power needs, flooring materials, ceiling materials, bench materials, housekeeping, and space for employee conveniences (e.g., break areas, restrooms, lockers, telephones, access to natural lighting).

- **The subcommittee understands the commenter's concern and has attempted throughout the guideline to effectively address basic issues in laboratory design. The subcommittee deleted the second paragraph of Section 3.1.1 with the exception of the last sentence which was moved to the end of the preceding paragraph.**

8. No specifications were included for the Frozen Section Room, biohazard waste storage, trash storage (especially boxes), clean and dirty laundry storage, glassware washroom, or autoclave room. No consideration was given for storage of glass slides, especially the weight considerations. No consideration was given for block storage or for the computer room.

- **The subcommittee believes that the revisions resulting from Comment 5 clarify that this document is intended to give general guidance and is not intended to replace a competent laboratory planner.**

9. In discussion of computer workstations, there should be provisions for at least 25% more cable lines than currently anticipated needs, and that every line have an extra 15-20 feet of cable length so that the line can be rerouted to another nearby area.

- **The following sentence was added to the end of Section 3.5.2: "Data outlets should be supplied in a manner that allows for adequate supply and flexibility."**

10. Although this may be addressed in another NCCLS document, power supply is important. There must be sufficient power to handle a multitude of instruments using both 110 and 220 volts. The problem of "clean" lines without surges is common and should be addressed from the start. Sufficient emergency power outlets are also mandatory.

- **The subcommittee added a new Section 4.7.3 that addresses electrical power.**

11. Air handling: re-emphasize that air emanating from biological hoods must be filtered or otherwise sterilized before venting. This, perhaps, should also be considered for air exiting from the morgue.

- **The subcommittee refers the commenter to Sections 6.1 and 6.2 which have been revised. Also, a sentence has been added to Section 6.2, *Conventional hood*, fourth paragraph: Information regarding specific standards for the various types of hoods should be obtained from specialized sources.[19]**

12. The NCCLS "Laboratory Design; Proposed Guideline" document (GP18-P) provides information that has a national and international application.

    Various regulatory agencies (CAP, JCAHO, CLIA, OSHA, etc.) evaluate laboratories relative to the utilization and adequacy or existing space. The design of a new laboratory, or the remodeling of an existing laboratory, needs to be carefully considered from the viewpoint of safety, testing requirements and their associated regulatory requirements.

There are a number of books available relating to laboratory design and planning. Many of these books are either too general or too specific in terms of practical "getting started" information needed for initial planning purposes. The NCCLS document highlights the aspects of laboratory design that are essential and should be carefully considered at the beginning and during the laboratory planning and implementation process. The references serve to provide more in depth information as needed.

It is easy to become buried and overwhelmed by a building or remodeling project. This type of guideline establishes a framework around which to work and expand upon as the project develops. As with other NCCLS documents, it serves as a concise introduction, guide, and organizational tool for accomplishing a specific task.

I feel this document will be very helpful for those who have prior laboratory design experience, as well as those who have no prior experience with laboratory design.

- **The subcommittee appreciates the comment.**

13. This document appears to be a useful document for the clinical laboratorian to utilize in developing and planning the layout of a new or existing laboratory. This document is straightforward and gives useful information to be used in formulating the amount of space necessary for equipment and personnel. It gives definitions, formulas, references, and is well written. It pays attention to regulatory requirements (i.e., OSHA, state and local building codes, etc.) and provides useful information for dealing with requests to administration. I am sure that there are things that one might find that this document does not address in designing a laboratory, however, I am not able to find any here. It is very complete.

- **The subcommittee appreciates the comment.**

14. I have found this document to be a thorough and complete guideline to laboratory design. Medical laboratory directors or supervisors involved with the planning of a new or remodeled laboratory will find this a valuable resource. The guideline may also be utilized to support and justify special design requests unique to laboratories.

- **The subcommittee appreciates the comment.**

Section 3.0

15. Section 3.0, Space, should include a subsection that recommends allocating space for biohazardous waste disposal receptacles (both countertop and floor receptacles), conveniently located to allow for safe disposal of both sharp items and waste material.

- **The following sentence has been added to the first paragraph of Section 3.2.2: "Consideration needs to be given to equipment for clerical tasks and to waste disposal."**

TABLE 1

16. What is the source for these space specifications?

- **Table 1, Reported Clinical Laboratory Space Figures, has been deleted, therefore the space specifications in question are no longer applicable.**

17. The space figures for "Procedures Performed" can be misleading. The definition of "procedures" should be added as many labs have various methods of quantitating their workloads. Due to the increase in outpatient testing, the calculations for net square feet per bed can also be misleading.

- **Table 1, Reported Clinical Laboratory Space Figures, has been deleted from GP18-A.**

Section 3.2.2

18. Storage for records and specimens that are to be kept for long periods of times should be addressed. Remote sites in the facility that can be used for this storage should be designed to meet the specific needs of the material being stored. Issues such as ventilation (e.g., specimens stored in formalin), structural strength (e.g., storage using "Space saver" types of components) and temperature (e.g., paraffin blocks) should be addressed.

- **The subcommittee refers the commenter to Section 5.2 which addresses the quality of storage space.**

Section 3.3

19. Do the authors mean "prevent" access or a more practical guideline, such as warn, placard as restricted, or limit access (e.g.,one-way doors). I have yet to see a hospital laboratory, or surgical suite for that matter, that actually prevents access by unauthorized persons. A white coat or briefcase can get you in almost anywhere!

- **In the second paragraph of Section 3.3, the word "prevents" in the underlined sentence was replaced with the word "controls."**

20. The definition of egress vs. nonegress would be useful to those not familiar with the terms. References to NFPA codes for egress corridors should be added.

- **To clarify the use of the word nonegress, the subcommittee revised the third sentence in Section 3.3 to read, "...,nonegress or required fire exit,..."**

21. Security alarms and intercoms for the safety of laboratory personnel have been added to the majority of the projects I work on. Some notation of this in relation to controlling access into the laboratory would be appropriate.

- **The following sentence has been added to the end of Section 3.3: "Intercoms and alarms are needed to inform or alert personnel (e.g., disaster or fire alert, pneumatic tube arrival, or for assistance elsewhere in the laboratory) and should be planned for in the laboratory design."**

Section 3.5.2

22. Computer networking has expanded to reference laboratories and doctors offices. When you talk to access it is no longer limited to the rest of the hospital. Some comparison of the advantages and disadvantages of various communication systems (such as fiber optics) would be useful to those setting up a new system.

- **The subcommittee considers this beyond the scope of the document.**

Section 3.6

23. It should be noted that many of the codes have significant impact on the laboratory floor plan and engineering systems.

- **The following sentences have been added to the end of Section 3.6: "Code compliance can significantly impact laboratory designs. Consequently, code compliance should be reviewed by an architect periodically throughout the laboratory design and construction process."**

Section 3.7.1

24. The planning team should also include selected laboratory personnel. The users are the most important part of the planning team.

- **The following sentence has been added to the end of the first paragraph: "It is essential that key personnel that are knowledgeable about the specific operational workings of the laboratory be part of the planning team."**

Section 3.7.2

25. Movement analysis and diagrams can be used to evaluate existing conditions as well as large and small changes in laboratory plans.

- **The subcommittee refers the commenter to Figure 5 in Section 3.7.6.1 of GP18-A which addresses movement analysis.**

Section 3.7.3

26. The definition of net and gross area should be placed here from 3.7.6.

- **Section 3.7.6 was moved and has become Section 3.7.4. The remaining subsections of Section 3.7 have been renumbered accordingly.**

Section 3.7.4

27. I would suggest that Section 3.7.4, "Equipment Listing," include a recommendation that the manufacturer's instrument specifications regarding space, location (e.g., accessibility to rear or side of instrument for maintenance and repairs) and power source (e.g., dedicated lines to provide uninterrupted power source) be followed. The current text that begins on line 6, page 5, states "The length and width are used to calculate the needed space in square feet, as shown in Section 3.8." Next, the following text could be inserted: "The manufacturer's recommended space requirement for the instrument may exceed the actual measured size, and should therefore be used in calculating the needed space. Access to the rear or side of the instrument for maintenance and repair may also be a manufacturer's recommendation, and should be considered when calculating the needed space (e.g., open counter space on the side or rear of the instrument)." The text that begins on Line 8, page 5, in the same section, could be expanded to include uninterrupted power sources. The present text reads "The voltage and amperage requirements are used to calculate power requirements and heat generation of the equipment for estimation of ventilation and cooling needs." The revised text could read as follows, "The voltage and amperage requirements are used to calculate power requirements (e.g., dedicated lines to provide uninterrupted power to major instruments) and heat generation of the equipment for estimation of ventilation and cooling needs."

- **The subcommittee believes the commenter offers good suggestions that strengthen the section and has incorporated these suggestions.**

28. In the required information for equipment, equal importance should be given to information on clearances, access, gases, plumbing, weight and emergency requirements. You could add an example of an equipment list. Calling manufacturers for specifications and keeping them in an updated notebook can save time and aggravation when any renovation is required. This could also save the expense of hiring an equipment consultant.

- **Section 3.7.5 has been revised to include the development of a notebook of equipment manufacturer specifications, and also incorporates the suggestions from Comment 27.**

Section 3.7.6

29. The term "lost space" can be misleading when referring to net and gross area. In a laboratory the large amount of mechanical space can make the net vs. gross seem high. In the layout of a laboratory actually adding a corridor can improve access to a necessary space and therefore increase efficiency. This should be investigated in any laboratory design to help minimize costs, but should also be related to the requirements of each individual space.

- **In Section 3.7.4, the term "lost space" has been replaced with "net usable space."**

Section 3.7.7

30. The Occupational Health and Safety Administration is currently writing the proposed OSHA Standard on Ergonomics that will be published before October 1, 1994. The subcommittee may want to contact OSHA in Washington, DC for valuable input to this section.

- **This standard has not been published yet.**

31. When referring to sizes of males vs. females I was concerned that someone would base the size of their laboratories on genders. The design should be based on the appropriate size to allow the procedure to be performed efficiently. Most laboratories have several people doing the same task at different times. The gender is likely to change. This reference also does not take into consideration the rapidity of laboratory personnel turnover.

- **The following sentence has been added to the end of this section: "As a matter of practicality laboratories should always be designed so that individuals of different physical size can work in them safely and effectively."**

32. This would be an appropriate place to refer to ADA standards and ergonomic guidelines.

- **The following fourth sentence was added to this section: "The design criteria should be in compliance with ADA requirements."**

Section 3.7.8

33. The guideline should include some comment about the need for pneumatic tube systems to improve laboratory productivity. I would suggest the following wording:

    3.7.8 Pneumatic Tube Systems - The efficiency of laboratory testing is impacted not by how space is utilized within the laboratory but by the physical size, that is the linear feet separating the source of samples and the laboratory, of the institution the laboratory serves. Investigation of the components of the total laboratory testing Turnaround Time (TAT), from ordering to resulting, typically show that the actual time from receipt in the laboratory to resulting (TRT) comprises less than half of the TAT. Often the majority of the TAT is due to the time consuming steps done before the sample gets to the laboratory, the preanalytical steps, and the TRT begins. One substantial component of this preanalytical step is transport of samples to the laboratory. Pneumatic tube systems enable individuals to direct samples ready to be tested to the laboratory and then move on to get more samples. Without a pneumatic tube system the individual must walk samples to the laboratory, often waiting until samples are collected from several patients, and then return to where the patients are to get more samples. The ability to get samples to the laboratory in a timely manner is an important consideration in deciding between main laboratory testing versus satellite laboratories or point-of-care testing options. An efficient sample transport system becomes increasingly important as the distance increases from where samples are collected to where they are analyzed in the laboratory. Most pneumatic tube systems used for transport of laboratory samples are 4" or 6" systems. Experience of others is the best guide to how well the various pneumatic tube systems actually perform with the type of samples to be used by a given laboratory.

- **The subcommittee believes that Section 3.5.2 which addresses pneumatic tube systems is adequate and within the scope of the document.**

Section 4.0

34. Section 4.0, Casework/Millwork/Furnishings, should include a reminder for industrial and research laboratories that compressed air, gas, and vacuum nozzle outlets will utilize some of the workbench space.

- **The following paragraph has been added to Section 4.1: "The planner should consider the impact of locating fixed utilities (e.g., gas, vacuum, air outlets) on counter surfaces. Locating these utility chases and reagent shelves frees up the work surface for other functions and improves flexibility."**

35. Some "stock" casework is installed so permanently that it is very expensive to move, and it has been my experience that many components become damaged in the actual demolition and cannot be reused. The flexibility of various types of casework should be evaluated by talking to the manufacturers and other laboratories that have used the products.

- **The subcommittee refers the commenter to the second paragraph of this section. Also, the following sentence has been added to the third paragraph of this section: "Discussions with actual users of the casework being contemplated is invaluable in deciding on the actual utility of the options under consideration."**

36. The personnel that actually work on the bench should be involved in the decision making. Often directors and pathologists that do not work in the laboratory proper every day decide what is best for the technologists. The end result is an unhappy work force and therefore an unhappy administration.

- **See response to Comment 35.**

37. Laboratory casework is included in the construction documents and specifications, as is millwork. The difference being that millwork is detailed to tell the contractor specific construction criteria. Casework is normally given performance criteria in the specifications, and possible specific stock numbers if only one manufacturer is being considered.

- **The following sentences have been added to the end of paragraph 2 of Section 4: "Casework is normally given performance criteria in the specifications, and possible stock numbers if only one manufacturer is being considered. Millwork however, is detailed to tell the contractor specific construction criteria since it, unlike casework, is often built for the customer."**

Section 4.7

38. "Fundamentals" discusses laboratory furniture. Two of the pages (11 & 12) missing from my copy were from this section, and therefore I don't know whether the issue of adequate desk space for computers is addressed. The section should include a recommendation to provide adequate height and depth of workbench space for computer monitors and keyboards.

- **The subcommittee refers the commenter to Section 4.8, the first three bullets under specifications for general workstations.**

Section 4.7.1.2

39. In researching casework you should also check on obsolescence, warranties and trade-in policies. This allows the owners peace of mind when they purchase such a large cost item.

- **The following sentence has been added to Section 4.2: "The planner should consider warranties, trade-in policies, obsolescence, scope of inclusive accessories (task lighting, etc), and actual field performance when selecting product."**

40. Note what is included with various brands of casework. Some companies will include lighting, wiring, outlets and various storage accessories. When a bid is requested from more than one manufacturer it is important to be specific on what is to be included so you can compare apples with apples.

- **See response to Comment 39.**

41. Monitors can be placed on adjustable arms mounted on casework, floors and walls. This gives maximum adjustability, frees the countertop for testing, and addresses ergonomic issues. As an added bonus, it protects the monitor from spills. The same logic applies to keyboard trays under the countertops.

- **The following sentence has been added to the end of Section 4.7.2.1: "The video display terminals (computer monitors) and keyboards may be mounted on adjustable arms which permit individualized placement of the monitors and uncluttering of work surfaces."**

42. Interferences from other instruments and on other instruments is becoming a significant problem (electromagnetic pollution). Proximity of computers to other equipment can cause problems to either piece of equipment, especially if it is a sensitive piece. Manufacturers should know if this is a potential problem with their equipment. We have found that in research laboratories this issue is a bigger problem than in clinical laboratories, but with the technological advances in both instrumentation and computers this could change.

- **The subcommittee appreciates this comment but considers it beyond the scope of the document.**

Section 4.7

43. Breaking the countertops into section can add to the flexibility, but it can also add to areas for potential microbial growth. This should be addressed for each particular situation.

- **The following sentence has been added to the end of the first paragraph of Section 4.7.4 (Former Section 4.7.3): "Another consideration is the potential for microbiological growth with particular countertop configurations which must be evaluated for the laboratory application involved."**

Section 4.8

44. The depth of the cabinets is not a good criteria for the amount of storage. Architects determine storage depth by linear feet, not square feet. Most people use the first 1'0" to 1'-6" for storage. The back areas are either empty or filled with things that should be disposed of. In storage rooms for laboratories that regularly rotate stock, deep storage shelving would be appropriate.

- **The last sentence of the second paragraph in this section was deleted.**

Section 5.1.1

45. I agree that laboratories must control inventory carefully but a more inclusive discussion of inventory control should probably be done in some document other than Laboratory Design.

- **The subcommittee refers the commenter to NCCLS document GP6—*Inventory Control Systems for Laboratory Supplies,* which is referenced in Section 5.1.3.**

46. The authors' management philosophy of "just-in-time" delivery needs deeper examination as it applies to clinical laboratories with varying workloads, marginal reliability of suppliers, and

emergency demands. We cannot "backorder" CSF cultures, gloves, and numerous other things. Although an "out" is provided in this section, my concern is that it is inadequately strong to deal with the realities of an increasingly cost-conscious administration. Not having adequate supplies on hand for emergency work could be deemed a "conscious decision" (see: section 3.1.1) by the laboratory director. Again, I think the document should stick to providing resource information for laboratory design and steer away from management opinions.

- **The subcommittee believes this information is appropriate for the scope of the document. This document is written for persons involved in laboratory design and involves management-level decisions.**

Section 5.2.2

47. Refrigerators and freezers kept in storage rooms and rooms designated for just those components must be noted in the equipment lists. The ventilation requirements to dissipate the heat generated is significant. If this is neglected not only will the room be hot, the energy costs will increase and the life expectancy of the equipment will decrease.

- **The following sentence has been added to this section: "Because freezers, refrigerators, and other equipment can generate considerable heat, the size of rooms in which they are located and the number of these appliances must be considered in determining ventilation and air circulation needs."**

Section 5.4.1

48. Page 17, "Nonrefrigerated Storage," addresses the issue of storage outside the working laboratory area. The text beginning on line 1 of this section states "Supplies and records that are not required in the laboratory area should be stored in an accessible location outside the working laboratory area." The text should be revised to include both accessibility and availability, and could read as follows, "Supplies and records that are not required in the laboratory area should be stored in an accessible location outside the working laboratory area, and should be available within a reasonable amount of time."

- **The subcommittee agrees and has revised this section to incorporate the commenter's suggestion.**

Section 5.5.1

49. I question the need for the statement on "political lip service." As frustrating as that may be to any laboratorian and administrator, I found it to be inappropriate to the technical aspects of this book. A statement that explains the importance of precise and complete research to the cost effectiveness and reasoning behind design criteria would be better.

- **The first paragraph of Section 5.5.1 has been modified by deleting "pay lip service to" and rewording the text.**

50. Adding information on life cycle cost analysis and the ability to project future construction increases would be helpful here.

    The addition of the implications of adding robotics to the laboratory should be added. Issues would be those concerning point loads, acoustics, space allocation and safety.

    "Core" laboratory layouts, and other changes in the traditional laboratory could be addressed.

- **The following sentence has been added in the first paragraph of Section 3.7.6.2: "Utilization of flexible casework would facilitate the installation of a robotic system at minimal inconvenience and cost."**

Section 5.5.3

51. As pointed out, decentralization can create an inventory control problem. However, detailed guidance on inventory control issues should come from another publication.

- **The subcommittee does not believe that Section 5.5.3 which addresses decentralization of storage is excessive and refers the commenter to *GP6—Inventory Control Systems for Laboratory Supplies.***

Section 5.6

52. I personally applaud including provision for emergency evacuation of handicapped/disabled employees. Suggestions on how this might be accomplished may not be relevant here but should be placed in an appropriate NCCLS document as this is a concern for those of us who have employees that fall into this category.

- **The subcommittee has referred this comment to the Area Committee on General Laboratory Practices to be considered in a future NCCLS project.**

53. Several excellent references are provided in section 5.6. A problem we have had recently is interpreting these requirements into practice, particularly when there seem to be conflicting specifications, which may arise in part from different revision dates for the codes. For example, what is the simple and practical answer on chain height and location for drench showers in a hospital laboratory that satisfies fire codes, ADA, and OSHA? Some practical guidelines in the document would help. It would also help to explain, when appropriate, the different requirements that may exist when a laboratory is in "hospital space" *versus* nonhospital space.

- **The practical guidelines that the commenter has requested have been addressed in the revised Section 3.7.6.3.**

Section 6.0

54. There is inconsistent information regarding air-handling requirements. On page 22 the document states "Current thinking advocates a minimum of 12 air exchanges per hour, with 16 exchanges considered more appropriate in some areas." The minimum air-exchange requirements in Table 10 on page 26 and Table 11 on page 30 are not consistent with the text or each other.

- **The "Air Changes Per Hour" column on Table 10 (Table 9 in GP18-A) has been deleted and the text in Section 6 has been revised.**

55. Overall, I think the information on estimating air handling needs is too detailed and not appropriate for the scope of this manual.

- **Section 6.8 has been revised; the subcommittee believes this information is appropriate for the intended audience of the document.**

Section 6.2

56. Hoods appropriate for tuberculosis should be addressed in this section. It is my understanding that the proposed OSHA guidelines for tuberculosis will be published in April, 1995. In addition, the matter of masks for tuberculosis has become quite controversial. I would recommend contacting NIOSH for assistance with this section. I understand some new regulations about masks came out in May and were presented at the APIC convention.

- **The subcommittee considers tuberculosis-related issues beyond the scope of this document. The following sentence has been added to Section 6.2, "*Biological Safety Cabinets (BSC)*:" "The planner**

should consult specialized sources for information regarding tuberculosis and other aerosol pathogens considered in laboratory design."

57. References should be made to the appropriate ANSI Standards for the varying types of hoods.

- **Reference 19 has been added to Section 6.2, under Conventional hood, fourth paragraph: "U.S. Dept. of Health and Human Services. Biosafety in Microbiology and Biomedical Laboratories. 3rd ed. Washington, D.C.: Public Health Services, U.S. Government Printing Office; 1993."**

Section 6.3

58. The proper application of variable air volume (VAV) boxes in the supply air can eliminate the need for booster coils.

- **The following sentence has been added to third paragraph of this section, "Alternatively, the proper application of VAV boxes in the supply air can eliminate the need for booster coils."**

Section 6.6

59. Discussion on negative pressurization and directional air flow to protect personnel and patients would be appropriate here.

- **A new paragraph has been added to the end of Section 6.4 that addresses directional air flow. The subcommittee also refers the commenter to Table 10 in GP18-A.**

Section 6.8

60. Calculations on pages 28-29 are very confusing and need to be simplified. Suggestion: list as Calculation Example 1, Calculation Example 2, or some other method. The section "4." doesn't fit the format of the rest of this section.

- **This section has been revised for clarity.**

61. Fume hood exhaust air volume is also based on lineal feet of sash opening and the opening height.

- **The following footnote has been added to the fume hood exhaust calculation: "Note: Fume hood exhaust air volume is also based on lineal feet of sash opening and the opening height. This information should also be taken into account when using this calculation."**

Section 7.0

62. Section 7.0— "Lighting," thoroughly covers lighting issues. However, there is no mention about the use of ultra violet light for sterilization purposes. I would suggest including a section that recommends having an ultra violet light source available for sterilization, especially in the laboratories with a virology section.

- **A new Section 7.4.5 which addresses specialty lighting has been added to the document.**

Section 7.4.2

63. Column 2, line 14: "(4,00 °C)" should be "(4,000 °C)".

- **The text is revised to address this comment.**

Section 8.1

64. This section does not address the amount of water needed for hand-washing, reagent preparation, and instrumentation. It should include advice on checking instrument requirements for water quality, pressure, quantity, and drainage.

- **The subcommittee believes the information presented in this section is adequate and within the scope of the document.**

References

65. Reference #6 on guidelines for accessibility can go after the last sentence of 3.6 (Code and Safety issues) concerning space.

- **The reference has been added as suggested.**

Related NCCLS Publications*

GP6-A **Inventory Control Systems For Laboratory Supplies; Approved Guideline (1993)**. GP6-A offers recommendations for inventory control systems to ensure the availability of reagents and supplies in the laboratory.

*Proposed- and tentative-level documents are being advanced through the NCCLS consensus process, therefore, readers should refer to the most recent editions.

NOTES

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