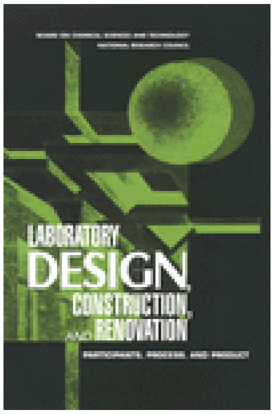

Laboratory Design, Construction, and Renovation: Participants, Process, and Product

Committee on Design, Construction, and Renovation of Laboratory Facilities, Board on Chemical Sciences and Technology, National Research Council

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LABORATORY DESIGN, CONSTRUCTION, AND RENOVATION

PARTICIPANTS, PROCESS, AND PRODUCT

Committee on Design, Construction, and Renovation of Laboratory Facilities

Board on Chemical Sciences and Technology
Commission on Physical Sciences, Mathematics, and Applications
National Research Council

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Preface

In response to concerns of the community of users and administrators of research facilities, the Committee on Design, Construction, and Renovation of Laboratory Facilities (see Appendix A) was appointed by the National Research Council (NRC) to provide guidance on effective approaches for building laboratory facilities in the chemical and biochemical sciences (Appendix B gives the statement of task). The committee members were chosen for their knowledge and experience in aspects of laboratory design, construction, and renovation and included scientist-users, facilities managers, providers of design services (architects and engineers), and experts in the specialized areas of environmental health and safety, hazardous materials, and community relations.

All of the members of the committee shared the community's concern about the problems of building laboratory facilities. Committee members' initial responses to the nature of these problems, possible solutions, and the content and style that the report might take were quite diverse. Following public meetings and presentations (Appendix C), however, the committee arrived at a consensus about these issues, deciding as a result to focus on how to have a successful laboratory facility designed and built, not on the details of laboratory construction.

The committee based much of its report on testimony presented during its first two meetings by scientist-users, administrators, and design professionals, as well as consultants in the areas of fire protection, compliance with Environmental Protection Agency regulations and the Americans with Disabilities Act, and building code. Committee members also heard a presentation from the entire building team of one project—including a scientist-user, facilities manager, director of physical planning, architect, administrator, and construction manager (see Appendix C). The committee is grateful to the many individuals who provided technical information and insight during these briefings. This information provided a sound foundation on which the committee based its work. In addition, committee members were able to draw on their own experience.

This study does not duplicate the numerous other publications on laboratory construction (see the bibliography). It is the committee's hope that scientist-users, institutional administrators, and institutional managers will use this report to become informed users of design services and that the professional design community will use this report to enhance its ability to interact with its clients.

This study was conducted under the auspices of the NRC's Board on Chemical Sciences and Technology. The committee acknowledges this support. The chair is particularly grateful to the NRC staff as well as the members of this committee, who worked diligently and effectively on a demanding schedule to produce this report.

John I. Brauman, *Chair*
Committee on Design, Construction, and
Renovation of Laboratory Facilities

Acknowledgment of Reviewers

This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the authors and the NRC in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The content of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

Gerald D. Begley, Eastman Chemical Company,
Jacob Bigeleisen, State University of New York at Stony Brook,
F. Peter Boer, Tiger Scientific, Inc.,
Ronald Breslow, Columbia University,
Lawrence D. Brown, University of Pennsylvania,
Ira Farber, Brandeis University,
Rebekah G. Gladson, University of California at Irvine,
Frederick D. Lewis, Northwestern University,
Ann Norberg, 3M,
Marion C. Thurnauer, Argonne National Laboratory, and
K. Peter Walter, Howard Hughes Medical Institute.

Although the individuals listed above provided many constructive comments and suggestions, responsibility for the final content of this report rests solely with the authoring committee and the NRC.

Contents

LABORATORY DESIGN, CONSTRUCTION, AND RENOVATION

Executive Summary

Laboratory facilities are complex, technically sophisticated, and mechanically intensive structures that are expensive to build and to maintain, and therefore the design, construction, and renovation of such facilities is a major challenge for all involved. Hundreds of decisions must be made before and during renovation or new construction. These decisions will determine how successfully the facility will function when completed and how successfully it can be maintained once put into service. Yet many of these decisions must be made by users and administrators whose knowledge of both basic and more laboratory-specific design, construction, and renovation is minimal at the start of the project and must be rapidly increased.

Laboratory design has been the subject of a number of books, including three previous studies by the National Research Council (NRC, 1930, 1951, 1962) and guidelines prepared by the National Institutes of Health and the American Institute of Architects (NIH, 1998; AIA, 1999). These books, however, are addressed to the professional design community, whose members are already familiar with general design and construction issues and processes. What has been lacking is both basic and laboratory-oriented information addressed to the user community—the scientists and administrators who contract with the architects, laboratory designers, and engineers who will design the facility and the construction personnel who will build it.

This report is addressed to the scientist-user and administrator, and therefore focuses on how to have a successful laboratory facility built rather than on the detailed specifications for a successfully constructed laboratory. In this context, a successful laboratory facility is defined as one that provides effective and flexible laboratories, is safe for laboratory workers, is compatible with the surrounding environment, has the support of the neighboring community and governmental agencies, and can be constructed in a cost-effective manner. This report covers many basic aspects of design, renovation, and construction projects in general as well as specific laboratory-oriented issues. In its discussion of the latter, the committee considered primarily chemistry and biochemistry laboratories; it did not deal specifically with specialized buildings such as animal facilities, nor did it address multiple-use buildings such as teaching and research facilities. (Narum, 1995, deals with teaching laboratories.)

Overall, the general principles elucidated by the committee make its recommendations applicable to the construction or renovation of almost any laboratory building. Through its investigations the committee found that although individual projects differ, there are certain commonalities in successful laboratory construction and renovation projects. These include the right participants and a continuity of personnel; a thorough, well-defined, and thoughtful process; and a broad knowledge of the relevant issues. These common themes are discussed in Chapters 1 through 3: "Human Issues," "Process Issues," and "Technical Issues." Many of these elements, especially those discussed in Chapters 1 and 2, may appear to be common sense, but they were found to have been overlooked in some of the projects described to the committee. Other themes are more specific to laboratory facilities.

Transcending specific issues and recommendations are four critical factors identified by the committee as characterizing successful laboratory construction or renovation projects:

1. A "champion" who is strongly committed to the success of the project, who has the confidence of the entire client group, and who stays with the project from beginning to end;
2. A design professional, often an architect, who has experience and demonstrated success in laboratory design and construction;
3. A well-defined and well-articulated process for carrying out the project from predesign through postconstruction; and
4. Clear lines of communication and authority for all participants throughout the process.

Attention to all of these factors is basic to achieving a successfully designed and built laboratory facility.

HUMAN ISSUES

Chapter 1, "Human Issues," discusses the participants, the sociology of building projects, and community relations. Participants are the people who play significant roles in a laboratory construction or renovation project. Some are part of the process by virtue of their institutional or external affiliations; others must be chosen to enhance the probability of obtaining a superior result.

The two most significant participants are the "champion" of the project and the design professional. The champion is important in articulating the need for the project and driving the project continuously from beginning to end. This person commands respect within the institution and has a direct line of communication to the administration of the institution. The design professional should have significant practical experience in the design, construction, or renovation of a laboratory facility with a magnitude comparable to that of the proposed project, and in the relevant scientific area. The selection of the right design professional is critical. If an externally imposed architect does not have these qualifications, a qualified laboratory consultant should be engaged.

Other participants required in a laboratory renovation or construction project include members of the client group (users, administrators, facilities operations personnel, budget authorities, environmental health and safety [EH&S] personnel, expert consultants), the design group (the design professional, engineers, consultants), the construction group (general contractor, suppliers), and the larger community group (the general public, regulatory authorities). The champion can be any member of the client group. Three members of the client group—the client project manager, the budget authority, and the user representative—form the client team, which is responsible for day-to-day management of the project. It is essential that some individuals, such as the users and the EH&S personnel, be involved in all phases of the project, especially the early planning; other participants may be involved in only some phases. Laboratory construction, like laboratory design, requires an attention to detail beyond that necessary for many building projects, and so the selected general contractor should have experience in the construction or renovation of technical buildings. The active and timely participation of all relevant parties is critical to completing a successful project.

The sociology of building projects has two aspects: the interactions between the participants involved in the construction or renovation, and the human needs that must be met by the completed project. Interactions are facilitated by effective communication and shared input. In particular, early user involvement often substantially reduces the number of costly change orders. The users' representative should facilitate the active participation of all users throughout the project, and the client team should manage the flow of information.

Human needs are met by design features, although no single set of design features suits all. Some design features reflect the basic philosophy of an institution, such as mixed use, shared versus individual laboratories, modular design, the relationship of offices to laboratories, the number and types of public spaces, and concerns of the community. Other design features address human needs and concerns, such as the location and quality of reading rooms and rest rooms, safe corridor design, and overall convenience, aesthetics, and security.

Good community relations are required for the successful siting, construction, and use of a new laboratory building. Such relations are best achieved through effective communication and the timely exchange of information with the surrounding community. This community should be actively engaged in a project early in the planning process through, for example, educational outreach efforts and the use of the institution's community and public relations offices, community advisory boards, chambers of commerce, and the local media. Paternalistic, technocratic, or secretive planning methods should be avoided. Continual interactions with an informed community afford an institution the best opportunity for good long-term relations with the community.

To address the human issues in a laboratory construction or renovation project, the committee recommends the following actions:

1. **Provide institutional leadership.** A person committed to the success of a laboratory renovation or construction project should be identified early in the project. This person will serve as the "champion" for the life of the project.
2. **Select an experienced design professional.** A successful laboratory construction or renovation project requires the services of a design professional with demonstrated experience and success in laboratory design and construction of the type and scale required in the project. If institutional constraints preclude the selection of a suitably experienced architectural firm, an experienced laboratory consultant should be retained.
3. **Involve the users at an early stage.** Users, through a committed user representative, should be involved in all phases of a laboratory construction or renovation project, with special emphasis on early planning. Mechanisms should be established to encourage the free flow of information among users and other participants.
4. **Choose an experienced general contractor.** Laboratory construction requires greater-than-usual attention to detail; prior experience with technical buildings enhances the probability of success.
5. **Consider sociological needs.** Physical layout can help or hinder interactions among all who will use a laboratory facility.
6. **Involve the community.** Stay in close contact with the surrounding community throughout the laboratory construction or renovation project. Make use of the institution's external relations offices and community advisory boards, and avoid practices that might interfere with good community relations.

PROCESS ISSUES

Chapter 2, "Process Issues," describes the processes that occur during the different phases of a laboratory renovation or construction project. In the architectural design and build method discussed in this report, the phases of a project are predesign or information gathering, architectural design, construction, and postconstruction. Although other methodologies for building facilities may be more expedient, the committee does not discuss them in this report because it believes that they are less likely to yield the desired attributes of good laboratory design.

Procedural guidelines for use throughout a construction or renovation project are also described in Chapter 2. Because of the number of participants who should be involved and the number and types of issues that need to be considered throughout the project, the design, construction, and renovation *processes* should be planned as carefully and thoughtfully as the laboratory facility itself. Essential procedures include implementation of a rigorous decision-making process, identification and engagement of the necessary participants for each phase of the project, and establishment of formal lines of communication and authority among these participants. The architectural design phase should include a mechanism for verifying the completeness and accuracy of all design and construction documents. In the construction phase, a procedure for strict control of the budget and of change orders should be established. Finally, before the project is completed, assurance that the laboratory was built and will operate as planned should be secured through building commissioning, and a plan for the future maintenance and operation of the laboratory building should be established through an owner stewardship plan. Throughout all phases, a single individual in each group should be identified as a primary point of contact and should be responsible for all communication among the client, design, and construction groups.

The goal of the predesign phase is to identify the project's scope and budget as well as all issues that could influence the subsequent design/documentation phase. Although predesign is often slighted in project budgets, experience has shown that its successful completion enhances the probability that the laboratory construction or renovation project will be completed within the prescribed schedule and budget. Sufficient funds should be allocated for this vital phase.

In the design/documentation, construction, and postconstruction phases most of the work is conducted by the design and construction groups. It is essential, however, that the members of the client group remain actively involved to ensure that the program requirements are being met, to control changes in the scope of the project, and to carefully review all design and construction documents. Although it is important for all projects, careful review of all construction documents is essential for mandatory low-bid projects, because in this situation only that which is specified in the contract documents will be built. It is also essential that the procedures developed at the outset to enhance and regulate communication be rigorously adhered to in order to maximize productive communication between different contractors and subcontractors and to minimize the number of contractor-initiated change orders.

To address process issues during the several phases of a laboratory construction or renovation project, the committee recommends the following actions:

1. **Develop a planning and decision-making process.** Planning should include all relevant participants. Decisions should not be revisited without cause.
2. **Implement a predesign phase.** Predesign, involving a design professional, maximizes end results.
3. **Designate a single point of contact for each group.** This individual will coordinate all information exchange within the group and with the other (client, design, and contractor) groups.
4. **Maintain control of the budget.** Detailed cost estimates should be completed and reviewed at the conclusion of each phase. A clear process for handling change orders should be developed before construction begins.
5. **Establish a system for rigorous review and approval of documents.** Design documents should be carefully reviewed and approved by the client group representative at the end of each phase.
6. **Establish and implement a process for building commissioning.** Building commissioning should include the production of operation and maintenance (O&M) manuals, updated construction documents ("as-builts") and drawings, systems testing, and training. There should also be a postoccupancy evaluation.
7. **Owners should be good stewards.** Beginning at the planning stage and continuing for the life of the laboratory facility, owners must provide adequate funding and staffing for operation and maintenance of the buildings.

TECHNICAL ISSUES

Chapter 3, "Technical Issues," presents some of the basic elements that must be considered in the design, construction, or renovation of a laboratory facility, such as health, safety, environmental, and building regulations, design details, and cost considerations. Regulations, codes, and ordinances, which govern many highly specialized issues, will inevitably influence every major decision of the project, and so attaining compliance mandates the early and continuing involvement of EH&S professionals and the establishment of a working relationship with regulatory authorities. While it is possible to delegate design and cost control decisions to the design professional, the active participation of an informed client greatly enhances the probability that a superior laboratory facility will result. For example, multiple design alternatives may exist to satisfy particular laboratory requirements; before one is selected, each should be considered by the appropriate teams or committees of participants. It is advisable that each technical issue be considered and resolved early in the overall process, before design decisions are frozen, to obviate costly later changes in design or construction. Because cost considerations will influence these decisions, initial and revised cost estimates should be obtained in the initial phases and throughout the project, so that cost decisions can be made in a rational manner. Finally, adequate contingencies should be allocated, because even with the best planning, some changes will be necessary.

To address the technical issues in a laboratory design, construction, or renovation project, the committee recommends the following actions:

1. **Appoint an environmental health and safety technical advisor.** An experienced EH&S professional is needed to advise the client team in all phases of a laboratory construction or renovation project.
2. **Establish communications with regulatory authorities.** Early in the project the institution should develop a working relationship with regulatory authorities whose approvals are necessary for various aspects of the project.
3. **Consider design alternatives.** Explore alternative solutions for fulfilling needs.
4. **Complete predesign before committing to a budget.** If possible, defer setting the budget total until completion of the schematic design phase, when the scope, concept, and special conditions of the project are determined.
5. **Obtain cost estimates.** Construction cost estimates should be obtained from at least two separate, experienced sources, and the estimates should be reconciled at the end of each phase. Develop a list of project cost items as early as possible. Carefully review all bids, and compare them to design-phase estimates.
6. **Set adequate contingencies.** Even with the best planning, some changes will be necessary.

1

Human Issues

A laboratory affects the people for whom it was built, other people who share the building, and other stakeholders in the community, and it is designed and built by yet another large group of people. To increase the probability of completing a successful laboratory construction or renovation, it is necessary to identify and ensure the active involvement of all the people who should be participants in the process. This chapter identifies these participants and discusses their interactions.

PARTICIPANTS

Success in a laboratory construction or renovation project depends on having the right people involved with the project at the right time. Some of the participants are part of the process by virtue of their institutional or external affiliations; others must be chosen to enhance the probability of obtaining a superior result. The two most significant of the latter set are the "champion" of the project and the design professional. But the identification and involvement of all participants and the importance of their selection cannot be overemphasized.

The participants involved in a laboratory renovation or construction project include four categories: a client group, a design group, a construction group, and a larger community group, each with internal (institutional) and/or external members. Table 1.1 lists the more significant members of each together with the phases of the project in which they participate. The titles of the individuals or the offices in which they work may differ from one institution to another, and in some institutions an individual may serve in more than one role, but all players are important. The members of a group or a collection of members of different groups will form teams or committees during different phases of the project in order to carry out the operations of that phase, but defined lines of communications within and between the groups should be maintained. Otherwise, confusion and low productivity will result in all areas of the project. Communications during the different phases of the project are discussed in Chapter 2.

Project Champion

The participants listed in Table 1.1 and the process described in Chapter 2 are all characteristic of successful projects. In addition the committee found that in these successful projects a figure emerged with special leadership qualities. Typically this person, called the champion in this report, is important in articulating the need for the project and driving the project continuously from beginning to end. This person commands respect within the community and has a direct line to the administration of the institution responsible for the laboratory. Since any member of the client group can take on this role, the function does not appear in Table 1.1. In academia, it is frequently a member of the group of users; in industrial and government laboratories it may be a staff person.

The champion may not be the same person as the project leader and may not be giving directions to either the design or construction groups. Rather, the champion provides inspiration to the project and, if necessary, uses her or his clout to advance the project. The champion is not part of the formal project structure described below, and the champion's role may actually involve working outside formal organizational lines.

Participant Groups

Client Group

The client group illustrated in Figure 1.1 is entirely internal, although expert consultants can be retained and are placed in this group. This group is composed of a "client team" that will be the core group; financially and administratively responsible persons; and critical auxiliary staff. The decision to undertake the building or renovation of a facility may require the approval of other individuals who are not part of the client team but who are in the client group. These individuals may include representatives from the administration (e.g., president, provost, dean, CEO), business office (e.g., vice president, chief financial officer, treasurer), development office, occasionally representatives from the trustees or scientific board of advisors, or even the shareholders of a company, or the U.S. Congress. While the approval of these executives is required to undertake the project, day-to-day management is normally delegated to the working group that in this report is called the "client team."

TABLE 1.1 Participants and Phases of Participation

	Phase of Project			
Participant/Function	Predesign	Design	Construction	Post-construction
Client Group (Internal)				
Client Team				
Project manager	X	X	X	X
User representative	X	X	X	X
Budget authority	X	X	X	X
Others				
Users	X	X	X	X
Administrators–senior, finance	X	X	X	X
Environmental Health & Safety officer	X	X	X	X
Facilities operations representative[a]	X	X	X	X
External relations representative	X	X	X	X
Special Consultants[b,c]	X	X	X	X
Commissioning Expert[b]				X
Design Group (External)				
Architectural and Engineering Firm[b]	X	X	X	X
Engineering firm	X	X	X	X
Consultants	X	X	X	
Engineers/Specialists HVAC, fire, ADA, EPA, codes, etc.	X	X		X
Facilities Programmer[b]	X			
Construction Group (External)				
General Contractor[b]			X	
Subcontractors			X	
Suppliers			X	
Suppliers[b]			X	
Larger Community Group				
Impacted Nonusers (Internal)	X	X	X	X
Public (External)				
Neighbors	X	X	X	X
Environmental groups	X	X	X	X
Government (External)				
Local	X	X	X	X
County	X	X	X	X
Regional	X	X	X	X
State	X	X	X	X
Federal	X	X	X	X
Public Utilities (External)	X	X	X	X

[a]Includes client's architect, design and construction, utilities, and operations and maintenance divisions.

[b]Hired by client.

[c]Includes environmental site assessor, geotechnical consultant, community relations expert, construction manager, and cost expert.

The client team consists of three people. The first is the project manager, who derives authority from the head of facilities operations. In large organizations this person is often an architect or engineer. The second is the budget authority, a person who can authorize major changes in the budget. This person derives authority from the financial administrator of the institution. The third is the user representative, who derives authority from a senior administrator of the institution. Often this senior administrator is the person who has discretionary power to assign space in the facility, for example, a dean or department chair in a university or a director of research in industry. The members of the client team, who derive their authority from different administrative units, often have different and potentially conflicting interests that must be resolved for a project to proceed satisfactorily.

The user representative is the connection to the users, the people who will occupy the facility. The committee found that many of the most successful projects had as the user representative a scientist-administrator who was not going to benefit directly from the project, was knowledgeable, had good judgment, and had the confidence of all participants. For large projects the user representative is often freed from other duties for the duration of the project.

It is essential to have a project leader who has qualifications and experience commensurate with the type and scope of the project and has operational authority and responsibility for the project. Because several members of the client group can take on this role, the function does not appear in Table 1.1. For large projects, this person will generally be the client project manager; for smaller projects, especially in smaller institutions, this person is often the user representative or is designated by the administration or management. The project leader is the center of decisions and communications and for most of the project acts as the single point of contact for other groups. Therefore, this person should be familiar with the entire program, should have some budgetary authority, and, most significant, must remain with the project from beginning to end in order to provide continuity. If the designated project leader is inexperienced, it may be advisable to provide suitable training for this person.

Users are the people who will ultimately occupy the facility. The extent of users' input into a project is very institution- and phase-dependent. Users often lack experience in laboratory design and may not know what to request or how to evaluate options. Obtaining a successful facility depends greatly on input from informed users, so an instructional process should be implemented early in the project to achieve this goal. See the section titled "Sociology" in this chapter and the "Predesign Phase" section in Chapter 2.

Other members of the client group include the institution's architect and representatives from environmental health and safety (EH&S), facilities operations (including campus utilities), and external relations (including public relations, legal affairs, publicity, etc.). The client group may also include special consultants such as a construction manager, environmental site assessor, geotechnical consultant, commissioning expert, community relations expert, insurers, technical risk managers, and acoustical engineer.

Because of the size of the client group, it is advisable to engage a construction management individual or firm, especially for large projects. It may also be advisable to engage an independent cost expert to work with the design professionals and the internal staff to properly evaluate what the costs will be.

It is also advisable to engage a building commissioning expert as a consultant to evaluate the finished product to ensure that it meets design specifications and operates as planned, and that the client's facilities management division knows how to run and maintain it. These independent commissioning firms can provide important added value in meeting these goals.

During the project the client group will form committees and teams with members of the design group, as discussed in Chapter 2. The active and timely participation of all involved parties is critical to completing a successful project. The qualifications of all professionals engaged in the project should be thoroughly reviewed.

Design Group

The predesign/design group, illustrated in Figure 1.2, is composed of an architectural firm (or an equivalent design professional firm), engineers, and special consultants such as fire specialists, environmental consultants, code consultants, and EH&S specialists. (Design professional firms include architectural, architectural and engineering (A&E), engineering, and laboratory programming and design firms. Whether the design work will be carried out by an architectural or a laboratory planning firm will depend on the expertise of the architectural firm engaged.)

Because laboratory facilities are complex, technically sophisticated, and mechanically intensive structures, the choice of a design professional firm is critical. To understand the client's needs and to know what is necessary for an effective laboratory, the design professional firm should have had significant practical experience in laboratory design, construction, or renovation. Thus the firm should have successfully completed at least one laboratory construction or renovation project *in the relevant scientific area.* The committee found that successful completion of a laboratory in one scientific area (medical laboratory or synthetic organic, for example) does not necessarily demonstrate competence for a laboratory project in another scientific area. Methods for finding appropriately qualified design professional firms include interviews with firms, visits to completed projects at other institutions, and consultation with previous clients of prospective design firms.

In selecting a firm, it is very important to ensure the engagement of a specific, experienced individual in the firm as well as the commitment of the firm to provide adequate resources for the project. It is also important to ensure that the architect implements a quality-control process. Sometimes there is institutional pressure to engage unproven or unqualified individuals or firms, a practice that the committee found to be a source of major problems. If a design professional firm lacking appropriate qualifications must be retained (e.g., because of institutional contracting policies), serious efforts should be made to ensure that the laboratory design work is handled by a qualified design professional firm. Additional advice on selecting a design professional is detailed in Appendix D. Finding and engaging the right laboratory design firm is one of the most critical steps in the renovation/construction project.

The design professional often selects the engineering or architectural and engineering design firm, which is another reason the correct choice of the design professional is critical to the success of the project. If the design professional firm is an architectural firm with in-house laboratory programmers, it may provide the architectural or A&E design services. If it is a laboratory programming firm, the A&E design may be done by the selected architectural firm, preferably one that has worked successfully with the selected laboratory programming firm. In any case, it is important that the engineering design firm be as highly qualified as the design professional, and that it be involved early in the design process, along with other appropriate consultants and experts in specialties such as fire, access and other facilities for the disabled, ventilation, and safety and environment. It may also be advisable to engage a consulting contractor for review of the constructibility of the proposed design. The selected design professional firm often recommends many of these other participants for the client's approval.

The members of the design group will form committees and teams with members of the client group, such as staff architects and facilities personnel, as discussed in Chapter 2.

Construction Group

The construction group, illustrated in Figure 1.3, includes the general contractor, subcontractors, and, in some cases, suppliers of specialized materials and equipment. For large or complex projects a construction manager is often hired by the client group and so is a member of that group. The construction manager is often more familiar with local building costs than the architectural design firm and therefore can better estimate the cost of the project as well as coordinate the different stages of the construction.

The choice of the general contractor is critical because laboratory construction requires an attention to detail beyond that necessary for many building projects. As is the case with the design professionals, the experience and previous work of potential contractors should be carefully evaluated. If project time is short, it may be advisable to involve the contractor at an early stage of the design process for input regarding the availability of materials and personnel.

In the construction phase, this group will form committees and teams with members of the client group including the project manager and appropriate representatives from the physical plant including maintenance and utilities. The building commissioning expert, a special consultant of the client group, may also be included.

Larger Community Group

The final group of participants critical to the process are stakeholders who are not members of the client, predesign/design, or construction groups. This group includes affected nonusers, as well as representatives of the community, government agencies, and public utilities.

Affected nonusers are members of the institution who are not in the client group but whose work will be affected by the project. They include, for example, occupants of adjacent laboratories, occupants of other floors of the building undergoing renovation, or occupants of neighboring buildings affected by noise or disruption of electrical service during the construction project.

Members of the community group include the neighboring community and other, more specific interest groups such as neighbors and nongovernmental groups who may have an interest in, and concerns about, the laboratory. Their concerns can cause difficulties if not addressed appropriately.

A number of government agencies are also included in the community group. These are "agencies having jurisdiction" and include local, county, regional, state, and federal representatives. They are concerned with zoning, code compliance, environmental issues, construction standards, etc., and they provide permits and inspections.

All these members of the larger community group need to participate in the process at an early stage because their own work and environment are affected by the project. The institute's offices involved in external relations can help to provide the interface between the project and the community and to ensure that information is transmitted clearly and effectively. When needed, EH&S staff can provide technical support to the external relations office.

SOCIOLOGY

The sociology of building projects has two aspects: the interactions between participants involved in the construction or renovation and the human needs that must be met by the completed project. Interactions are facilitated by effective communication and shared input. Many of the problems that arise in a building project are due to lack of interest, experience, or knowledge on the part of users, lack of understanding of specific user needs by designers, and potential mistrust among other stakeholders in the community. This section provides suggestions to organize and facilitate efficient communication between diverse parties at different phases of a laboratory construction or renovation project.

The human needs of the project are met by design features. These include items that reflect the basic philosophy of the institution, such as mixed use, shared versus individual labs, modular design, relation of offices to labs, number and types of public spaces, and concerns of the community; and features that address human needs, such as location and quality of reading rooms and rest rooms, safe corridor design, and overall convenience, aesthetics, and security. These design considerations are discussed below.

Need for Shared Input

Human interactions affect building projects in diverse ways. This section deals with the need for and means of involving a diverse group of people in the planning, design, and construction of the project. Here the committee focuses primarily on the client group and specifically on the client team and how it must interact with users and other institutional groups as well as outside parties.

Relationships between the many different groups of people involved in a building project are extremely important. Users, building maintenance staff (including engineers, mechanics, service technicians, and janitors), administrators, executives, architects, builders, and community members all need to have the opportunity for open communication. Their participation is essential both for useful and necessary input and for imparting a sense of ownership to the people who will use or who may be affected by the facility. It may be a challenge to achieve this level of communication while maintaining clear lines of responsibility and reasonable efficiency in the process, but early and continued user involvement often substantially lowers the number of costly change orders. The client team can structure the flow of information and ideas because its members represent the separate facets of the project, as discussed in the "Participants" section of this chapter. Continuity of project leadership is extremely important and should be maintained to the greatest extent possible. Communications with the community is discussed in the "Community Relations" section of this chapter.

All users have ideas about how their laboratories and offices should be organized, but few have been involved in the design of new facilities. Many directly transfer their current situation, no matter how it evolved, to design ideas for new facilities. Thus input into the process and aspirations for the completed building are strongly influenced by personal and local history. Because users can provide useful insight into possible near- and long-term uses and research directions, they should be encouraged to assess both current and future needs. The committee strongly recommends that users be centrally involved in all phases of the building process and that responses be given to all users' questions, suggestions, and ideas. However, for their input to be effective users need to be exposed to new and alternate ways that buildings and facilities can be designed to meet their needs. Focus groups and visits to other sites are one way to generate ideas and provide examples to be emulated or avoided; other ideas are presented in the "Design Considerations" section of Chapter 3. To ensure an understanding of financial constraints and to base the project on realistic aspirations, users should also be included in budget presentations and discussions from the start. Later in the process it is extremely useful to help users visualize the final product through, for example, the use of three-dimensional computer-assisted design technology or the construction of full-scale laboratory mockups. Successive designs resulting from comments and suggestions should always be shown. Reasonable interaction of users with architects and design professionals should be allowed, and suggestions should be solicited and responded to. The cost of helping users see and understand what will be built before construction has begun will be recaptured many times over by minimizing costly change orders.

No single size fits all. A uniform design strategy cannot be dictated. Different laboratory uses will require different laboratory specifications. Specific needs can include the handling of wet, dry, toxic, and biohazardous materials; elimination of vibration; and provision of clean power, pure water, and filtered air. Solutions to these needs will be further influenced by the different cultures found in academic, industrial, and government research settings. But the need for communication and the need to include everyone at some level of the process is common to all projects. As an important bonus, the involvement of more minds in the process will add substantially to the total institutional memory, which may be called on for subsequent renovations or other related projects.

Role of the User Representative

The user representative on the client team facilitates users' involvement in the process from start to finish and provides a conduit of information to the administrative authority that will be concerned with overall management of the completed project, such as a college dean, department chair, or research director. This person, typically selected by the administrative authority from among the users, should be someone who recognizes the need to assemble and articulate users' thoughts and needs and who has the respect and confidence of the users.

The user representative should interact with all users in an efficient and open manner. Although it is important to actively include all users in planning, often the number of people and the range of needs are large and diverse, causing input into the planning of large projects to be extremely inefficient and to become so ineffective that busy people lose interest and cease to be involved. This problem can be addressed by creating some form of organization to provide a hierarchical grouping of voices. On the other hand, especially in institutions in which hierarchical structure is the norm, it is critical that all members of the unit understand that they have a part in the planning process and are encouraged to participate. Users can be grouped by shared facility needs or common interests; for example, floors or wings of the building can be established around subgroups that normally use similar techniques or study common problems. The users can then meet in these groups for planning and review sessions during the life of the project. It is often useful to make the laboratory design reflect these associations. If such a set of subgroups is established, a spokesperson can be selected from each to meet on a regular basis with representatives from the other groups, ensuring the sharing and pooling of ideas from all users while holding the process to a reasonable number of people. This interaction can lead to a heightened appreciation and understanding of the work of members of other subgroups and may even be useful in planning the siting of diverse groups within the building. The user representative should organize this entire effort, chair meetings of the group representatives, and ensure that users' input is included in the design of the building. In this way all users have direct involvement in the project, but everyone need not meet with all parties all of the time.

All parties should be kept informed of the progress; the client group should consider issuing some form of newsletter, possibly by e-mail, in addition to making occasional formal presentations to all the users. Even during the construction phase, user review and feedback can prevent mistakes in interpretation of desires and can, within reason, keep the project up to date with changing needs or personnel.

Building renovation projects share many of the needs of new construction but require careful additional attention to transition needs and plans for temporary housing during the project. Will some people have to make multiple moves? Is the schedule carefully worked out with input from all affected parties to minimize problems or at least avoid perceived unfair variations in degree of inconvenience?

Final Product Considerations

Acceptable designs reflect the specific technical concerns of the users as well as the needs and desires of the institution and will thus vary from project to project. (Some of these details are discussed in the "Design Considerations" and "Environmental Health and Safety" sections of Chapter 3. Cost implications are discussed in the "Research Laboratory Costs" section of Chapter 3.) In the ways indicated below, however, all buildings affect how people work with and relate to other people in their immediate and daily environment. Some of the topics discussed here might be addressed at one time for all the members of the client group; others might be covered in each or only some of the subgroup meetings. Some involve policy decisions that should be made before the basic plan for the project is initiated; others can be accommodated at later stages.

Internally Focused Issues

Mixed Use and Physical Layout. The utility of and problems associated with mixing functions such as formal teaching and research, research in diverse disciplines, or research that uses very diverse technologies or reagents should be considered in planning the renovation or construction of a laboratory facility. The building layout can encourage beneficial cross-fertilization or, if necessary, can isolate groups or functions that might have a negative impact on each other because of traffic flow, vibration, physical or biological contamination, or other factors. The effects of physical layout on daily encounters (horizontal versus vertical) and collegial interactions should also be evaluated. These basic planning issues should be considered early in the overall process.

Shared Resources. The advantages and disadvantages of open laboratories, in which the personnel associated with principal investigators working in related areas share a large open space and common equipment rooms, should be considered at the earliest stages of planning. Proponents argue that both efficient use of space and constructive interactions occur in this arrangement, although the issues of how many research groups can productively and safely share a common equipment facility and how such areas might be administered and maintained must also be addressed, as must decisions regarding the scale and organization of efforts to meet common needs such as glassware washing, chemical and other storage, and stockrooms. Thus, although building-design exercises can actually drive organizational changes, it is extremely important to understand and anticipate the impact of space use on local group dynamics in order to avoid unfortunate and counterproductive organizational schemes.

Offices. The quality and size of offices, including issues such as number of windows, whether they can be opened, who gets a separate office, and the relationship of the office to the laboratory (e.g., directly associated versus clustered with offices of other people doing similar work), can have a major impact on both efficiency and morale. Decisions about the relationship of offices to laboratories are fundamental and usually affect the design of the whole building, and should therefore be attended to early in the predesign phase. Similarly, solutions to the office needs of technicians, graduate students, postdoctoral fellows, research associates, and other professional staff can range from all offices sited in the laboratories to separate offices adjacent to the laboratory or, as for the faculty/scientists, clustered offices in spaces separate from the laboratories. While specific finishes and amenities will vary depending on the culture of the organization, electronic communication connections are common, essential, and changing so fast that added expense here, to provide excess capacity and thus future flexibility, is a worthwhile investment.

Degree of Uniformity/Flexibility. Although there are often real savings in strict modular design, some level of custom design might be considered to allow individuals a certain degree of self-expression and thus increase overall morale. Some of this individual design might be accommodated in portions of laboratories and offices without either compromising modular design or adding to cost. Simple ways to achieve individuality include user specification of paint or fabric colors.

Personal Workplaces in Laboratories. The amount and types of private space for laboratory workers should be considered, including design features such as partitions for privacy, lockers or locking cupboards for personal effects, and telephone and computer network outlets to satisfy both current and projected communication needs. Extra conduits or other provisions for future connections should be considered to accommodate growth and change.

Assembly Areas for Building Occupants. The building should include places where people can eat and meet in locations separate from laboratories. Effective planning requires a basic understanding of the kinds of formal and informal meetings the organization encourages. Planning should address whether there are special technical needs for meeting spaces, such as video conferencing capabilities, and the number of meeting and seminar rooms (the latter is often a special problem in industrial settings where classrooms are unavailable to fill in for this function). If workers have meetings where food is offered, planners must determine the organization's attitudes and policies concerning eating facilities (in descending order: dining room/cafeteria, kitchen, vending machines, microwave, coffeepot), including provisions for food-only refrigerators in work areas, even if there is a cafeteria, to allow workers who bring food from home to eat with others who buy their food. Subsidized food service has been found to be a useful way to keep workers on site and promote cross-fertilization of ideas. The building design should create opportunities for informal and spontaneous interactions; for example, markerboards in hallways or in niches can be very useful in promoting serious conversations in these settings.

Access Control. Access control is necessary in areas presenting health or safety risks. However, plans should be no more restrictive than necessary lest the impacted laboratory personnel abandon them. This issue is discussed further in the "Environmental Health and Safety" section of Chapter 3.

Library/Reading Room. The library or reading room should be comfortable and easily accessible at all times, and should contain provisions for future expansion of electronic capabilities. For a new building, the occupants should consider how they will organize and maintain the books and other resource and reference materials. They should explore design elements, such as storage or workspace, that will make maintenance of the collection easier.

Rest Rooms. Rest-room design should go beyond code considerations to ensure that the restrooms will be convenient and in locations deemed fair and accessible to all. Whether there is interest in, and/or a need for, a shower room(s) in the building, should be determined.

Corridors. Corridors should be sensibly scaled to make passage comfortable, but not so large as to encourage future fire code violations, such as use of the extra space for inappropriate storage or to place furniture. This situation illustrates the potential pitfall of a design feature that appears attractive at first but later becomes a nuisance. Long corridors should be avoided and, if possible, natural light should be provided to each major corridor.

Security. Interior and exterior lighting plans should be developed that are adequate for secure passage after dark. Outside pathways should be safe at all times. Additional items that must be addressed include a keying plan, with a hierarchical system of passkeys; plans to make the building both secure and accessible to the users; and, depending on the building context, possibly other, extraordinary provisions for added security.

Maintenance. Planners should seek surfaces, materials, and fixtures for both laboratories and offices that are easy to maintain, because many institutions have inadequate budgets for long-term maintenance. Although more expensive, it may be worth considering longer lasting, easily cleaned wall finishes, especially in laboratories. Planners should ensure that light fixtures can be reasonably maintained and take into account the daily needs of the maintenance staff.

Externally Focused Issues

The Community. The needs and concerns of affected neighbors must be addressed. It is therefore important to include discussions with relevant people about the final impact of a laboratory building or renovation project on both institutional and external neighbors. Issues to keep in mind include traffic congestion, the possibility of jealousy or envy of the new facility felt by other members of the institution, pollution, and any potential misunderstanding (occasionally fear or mistrust) of the facility's function, hazards, and aesthetic fit. Ways to engage the community are discussed below in the section "Community Relations."

Public Identity/Outreach. Depending on the mission of the institution and the amount and kind of traffic entering from outside the building, it may be worthwhile to include a public area for posters or other displays that inform visitors of the work going on in the laboratory facility. Some buildings contain a small museum or other organized display area. At the least, many buildings provide areas for the display of current posters from meetings, increasing collegial understanding within the building. Posted directories, possibly including photographs, are often useful, as is signage that makes it easy to find personnel and facilities.

Aesthetic Environment. Planners should give thought to color schemes and light levels beyond minimal standards. Appropriateness of specific task lighting should be discussed with the users. A landscape plan that provides enjoyable plantings and furniture that encourages outdoor gatherings should be sought, if appropriate. Window treatments should be pleasing but practical, and a plan to include artwork in the building should be considered (for example, some university museums lend paintings and sculptures to buildings).

Access from Outside. It is usually necessary to include a parking plan. If appropriate, efforts should be made to ensure handy connections to other transportation options, such as easy access to bus stops or other forms of mass transit, and adequate bicycle parking.

Pollution Prevention. Planners should formulate a plan for convenient removal of the different kinds of waste likely to be generated in the facility. They should determine if there is an institutional practice (or even facility) in place for shared use of used and unused reagents, and if there is a recycling plan. Laboratory waste regulations, management, and storage are discussed in Chapter 3.

Equal Access. As mandated by the Americans with Disabilities Act, the needs of physically impaired users must be addressed. Often early planning with users' input can meet this requirement without incurring excessive extra costs or compromising the effectiveness of the project.

COMMUNITY RELATIONS

Successful siting, construction, and use of a new laboratory building require effective communication and information exchange with the surrounding community, just as they do with the internal stakeholders in the process. Neglect of the community's concerns and opinions may create delays, increased costs, and, in a worst-case scenario, laboratories that cannot be occupied (for an example of such a case in San Francisco, see Piller, 1991).

The construction of laboratories has not usually encountered the same level of neighborhood and environmental objections as have other projects—for instance, hazardous waste facilities, power plants, or low-income housing (Popper, 1991). A few communities—notably those with large populations of scientists and engineers—may show little concern at the prospect of an environmentally well-designed laboratory being built. But others may be more apprehensive, less trusting, or both. Community concern about laboratory construction will probably continue to increase because of the growing number of laboratories; the public's widespread fear of chemicals and biohazards; its growing awareness of environmental issues, such as air pollution; and its annoyance at the hazards and inconvenience of all large construction projects, such as increased traffic problems. In some locations, if a community seriously resists a laboratory, it will not be built (*New York Times*, 1999). Effective community relations can prevent this outcome by legitimately allaying community concerns.

There are many legal requirements for community involvement, discussed in detail in the section "Environmental Health and Safety" in Chapter 3. These requirements include a federal environmental assessment (mandated by the 1969 National Environmental Policy Act when construction necessitates federal financing or licensing); analogous requirements in most states when state funding or licensing is needed; local land-use ordinances; and federal, state, and local air pollution, water pollution, hazardous waste, and historic and archaeological preservation laws. At the same time, the required community involvement offers the institution building or renovating a laboratory an opportunity to deal constructively with the community's concerns.

In addition, even if the institution is relatively self-contained, the community generally takes part in emergency planning for the operating laboratory building if a laboratory emergency or some other form of emergency is likely to have an impact on it. Under Title III of the 1986 Superfund Amendments and Reauthorization Act (SARA), facilities whose levels of hazardous waste exceed set thresholds must let potential outside emergency responders know what substances exist in the facility (see the section "Environmental Health and Safety" in Chapter 3 for further discussion of regulations).

Thus, representatives of the external community must be among the participants throughout the project, beginning with its earliest planning phase—and preferably with the institution's development master plan—before the construction project even begins. Although, in the past, institutions seeking to build laboratories could ignore the surrounding communities, this approach no longer works—tactically, ethically, or environmentally—for either the institution or the community.

Helpful Practices and Resources

By far the best method of ensuring the completion of a proposed laboratory facility is to actively engage the surrounding community early in the planning process. Moreover, even apart from building or renovating laboratories, continual interactions with an informed community affords an institution the best opportunity for long-term good-neighbor relations. Adversarial interactions may occur and some opposition groups may never be satisfied, but negative reactions to new laboratory construction often reflect a basic failure by the institution to engage and inform the community in the first place. Resources and mechanisms for beneficial engagement and information exchange are suggested below.

The Institution's Community Relations and Public Relations Offices

The advice of community relations and public relations offices should be sought by a renovation or construction project's leaders early in the project, and these offices should remain involved throughout. In many situations one of them may be the institution's lead unit in responding to the community, and some institutions may want to formally designate the lead unit. For sensitive projects, it may also be advisable to provide media relations training to the project leader.

Community Advisory Boards

The community may establish an advisory board, consisting of respected community participants, to take part in the institution's planning process by meeting with high-level institutional representatives. Such a board can, for instance, express community responses to proposed institutional plans and changes in them.

In-house Advisory Boards and Related Mechanisms

The institution can use its staff to gain insight into community concerns about the proposed facility project, especially if some staff members share those concerns. An in-house advisory board is one possibility. Another is the use of staff members who are established, respected members of existing community organizations as liaisons to such groups.

Consulting Firms

If the institution's community relations and public relations offices lack resources, laboratory construction is new to the institution, or community sensitivity is expected, the institution should consider hiring a consulting firm specializing in community involvement and/or environmental impacts. Such professionals are experienced in recognizing potential sources of opposition and recommending responses. For a small fraction of the design costs, the institution can substantially reduce the chances of unfortunate incidents. Community relations consultants can often be useful beyond the design stage—for example, in reducing change orders and promoting long-term goodwill between the institution and the community.

Educational Outreach

Science education initiatives aimed at the community, such as open houses or programs in science education for teachers and children from the local schools, parent-teacher groups, or the community at large, are an excellent institutional investment. It is worthwhile for the institution to get to know the individuals in charge of local public schools and their special needs. In general, the institution's entire staff should be encouraged to participate in such outreach.

Chamber of Commerce and Similar Groups

The local chamber of commerce and similar groups can facilitate interaction with the local business community. Their meetings can provide an opportunity for communicating the institution's missions and for learning about the business community's concerns. Speakers who can clearly convey the economic and nonmarket values of the institution's research should be made available for such meetings with local leaders.

Anticipatory Actions

It is vital that the institution be aware of any groups that may have objections to laboratory construction. The institution needs to study the groups' positions and participants so that it can foresee their reactions and plan its response accordingly. In many cases engaging the organizations in public or private dialogue about the project has proved to be more mutually beneficial than the institution or the organizations expected. Other forms of anticipatory action might include keeping in close touch with government officials and using role-playing sessions to prepare for community meetings.

Local Media

The institution should provide positive information about its activities, ranging from scientific discoveries to staff recognition (such as national awards) to community contributions (such as food and blood donation drives, participation in the United Way) to the local media. The institution's past relations with the local media may influence the coverage of future stories.

Ongoing Regulation

The existing network of environmental laws provides formal mechanisms for informing the community and eliciting comments from it. In addition, the institution should maintain good relations with its regulators, advise them early of any projects that will require their attention, and perhaps request their input before it is legally required. These issues are discussed further in the section "Environmental Health and Safety" in Chapter 3.

Consultation with Comparable Institutions

The institution should contact similar organizations that have recent laboratory construction experience to learn of the measures they took to interact with their community. What did they do right? What did they do wrong? What would they do differently?

Rumor Control and Risk Communication

The institution should keep the community informed of any potential risks the site poses, both to prevent misleading information and to promote credibility with the community. An office or staff member should be designated by the institution to track local reactions and publicize a hotline, Web site, or other points of contact through which the community or other interested parties, including the institution's own staff, can obtain accurate, timely information. All questions about the new facility should be directed to the designated office or spokesperson.

Master Planning

A publicly posted comprehensive plan for the site, the institution as a whole, or both can inform the surrounding community of the institution's intentions and changes in them. Such plans might include renderings or scale models of the future site that the institution can exhibit in its lobby or at a community open house.

Emergency Planning

In the event of accidents at a laboratory, the institution must have in place an emergency response plan and a team to carry it out. The plan and the team must comply with all relevant federal, state, and local laws, and the institution should inform the community in advance of its compliance actions. In California, for instance, facilities with more than 55 gallons of hazardous material must annually submit a hazardous-materials inventory and a site map to the local emergency response agency.[1] Elsewhere the extensive and detailed emergency plans and teams of manufacturing facilities may offer useful models for less experienced laboratories. These approaches typically designate one office or spokesperson as the prime point of information or community contact in an emergency.

Practices to Avoid

Some institutional practices can harm community relations by antagonizing the community, the regulatory agencies, or other parties. Such practices usually increase opposition to the institution's construction activities (and to its other activities as well). Examples of such practices are given below.

Engaging in Paternalistic, Technocratic, or Secretive Planning

In designing and building laboratories, clear and thoughtful communication with the surrounding community is essential. Paternalistic, technocratic, or secretive planning underestimates the power and interests of the community and projects an attitude of arrogance that typically backfires. Community members should feel that the facility's construction was done with the community, not in spite of it.

Ignoring Past Difficulties

The consequences of the institution's previous conduct toward the community, such as incidents of toxic dumping, well contamination, chemical explosions or fires, or releases of poisonous gases or radioactivity, will heighten local sensitivities to the risks the laboratory poses. Sensitivities may exist even if incidents happened at distant facilities, and will understandably be higher if the incidents occurred at a nearby laboratory operated by the institution that is now proposing another one. In such situations it may not matter much if the institution has changed leaders since a time of difficult community relations; local memories tend to be longer. Neighborhood or environmental groups formed because of previous incidents will inevitably focus their attention on a new project. The past cannot be undone, but careful and respectful community relations, as detailed above, may help mitigate future difficulties. It is the burden of the institution to prove itself to the community.

[1] California Health and Safety Code, Chapter 6.95, section 25501-25505.

Neglecting Community Differences

To some communities a laboratory built by an environmentally responsible institution is highly desirable because of the jobs and other economic development chances it offers. In other communities, entrenched local economic interests may object to a promised laboratory because it will increase the cost of labor in the community or otherwise alter existing economic arrangements. Variations in communities' attitudes are often linked to their economic status, but they may also depend on such factors as geographical location, political environment, and ethnic or racial makeup. It is important that the institution anticipate community reaction correctly.

RECOMMENDATIONS

To address the human issues in a laboratory construction or renovation project, the committee recommends the following actions:

1. **Provide institutional leadership.** A person committed to the success of a laboratory renovation or construction project should be identified early in the project. This person will serve as the "champion" for the life of the project.
2. **Select an experienced design professional.** A successful laboratory construction or renovation project requires the services of a design professional with demonstrated experience and success in laboratory design and construction of the type and scale required in the project. If institutional constraints preclude the selection of a suitably experienced architectural firm, an experienced laboratory consultant should be retained.
3. **Involve the users at an early stage.** Users, through a committed user representative, should be involved in all phases of a laboratory construction or renovation project, with special emphasis on early planning. Mechanisms should be established to encourage the free flow of information among users and other participants.
4. **Choose an experienced general contractor.** Laboratory construction requires greater-than-usual attention to detail; prior experience with technical buildings enhances the probability of success.
5. **Consider sociological needs.** Physical layout can help or hinder interactions among all who will use a laboratory facility.
6. **Involve the community.** Stay in close contact with the surrounding community throughout the laboratory construction or renovation project. Make use of the institution's external relations offices and community advisory boards, and avoid practices that might interfere with good community relations.

2

Process Issues

Laboratory facilities are complex, technically sophisticated, and mechanically intensive. Constructing or renovating them requires careful planning guided by an experienced design professional. During the planning and construction phases, a great number of decisions will have to be made. To ensure a rigorous decision-making process, formal lines of communication and authority among the participants should be established early in the planning stages. As the project progresses, it will become necessary to establish mechanisms for other aspects of the process, such as rigorous reviews of design and construction documents, and a document approval process. It is also necessary to establish mechanisms for controlling budgets and change orders. Finally, before the project is completed a plan for the future maintenance and operation of the building should be established through an owner stewardship plan and building commissioning. An overview of a typical time line for these processes is given in Figure 2.1.

Because the processes of designing and constructing a laboratory building are dominated by the activities of the design and construction professionals, this chapter is divided into sections that correspond to the professionally designated phases of a project: predesign, design/documentation, construction, and postconstruction. It is, however, essential for the facility's owner, users, and other individuals collectively known to the design professional as the client to understand the responsibilities and limitations of the design and construction professionals and the means by which the client can most meaningfully contribute to the success of the project.

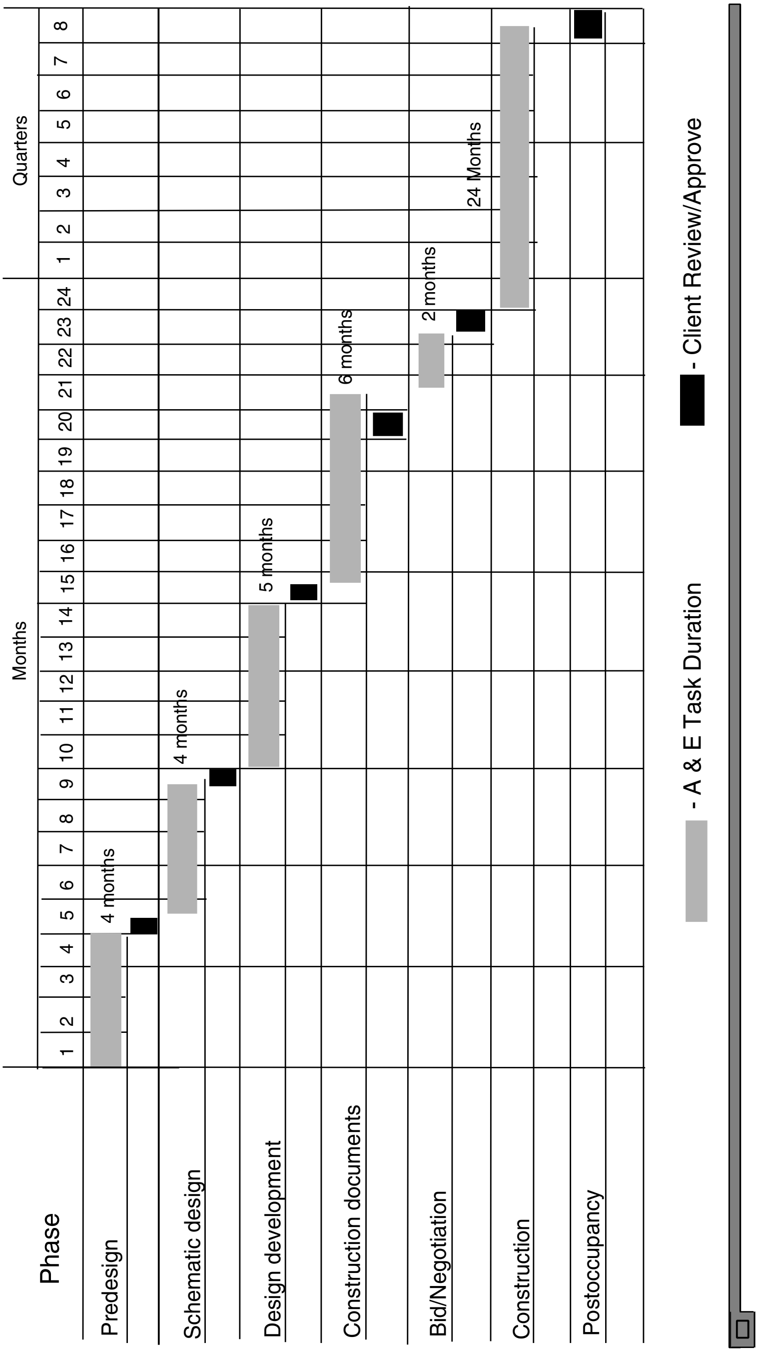

FIGURE 2.1 Sample project time line for new research laboratory building with a gross area of 150,000 square feet. The project time line will vary depending on the individual situation.

PREDESIGN PHASE

The goal of the predesign phase is to identify the project's scope and budget as well as any issues that could influence the subsequent design/documentation phase. Although this phase is often slighted in project budgets, experience has shown that its successful completion enhances the probability that the construction or renovation project will be completed within the prescribed schedule and budget. Sufficient funds should be allocated for this vital phase.

The predesign phase often includes an inventory and evaluation of existing facilities, identification of facility program requirements, development of preliminary planning alternatives, and completion of preliminary cost estimates. The predesign phase for a particular project should be coordinated with any strategic or master plan previously developed for the institution. If a strategic or master plan has not been developed, the predesign phase could be used to initiate the development of such a plan.

Procedural Guidelines

Due to the complexity of laboratory facilities, the design, construction, and renovation processes should be planned as carefully and thoughtfully as the laboratory facility itself. This applies to all phases of the project—predesign, design/documentation, construction, and postconstruction. Careful planning is required because of the number of individuals that should be actively involved in the processes as well as the number and types of issues that need to be considered throughout the project.

Decision-Making Process

Decisions made during the predesign phase set the direction for the entire design/documentation phase and subsequent construction or renovation. The client should therefore develop early on a decision-making process and establish lines of communication and authority that will serve throughout the project. Committees and decision-making processes and authority should be established to ensure appropriate input and participation. For example, decisions related to laboratory components will need the input of researchers, whereas decisions related to the number of laboratory modules will need input from administration representatives.

Participants and Participant Responsibilities

The number and types of participants will vary from project to project. However, many projects require a minimum number of groups and teams. Principal among these are the client group (which includes the client team, client senior administrative and financial officials, environmental health and safety (EH&S) personnel, and representatives from the facilities/operation and planning departments) and the design group. These teams and groups are described in the "Participants" section of Chapter 1. The role of the individuals within the client group is to provide input for various components of the predesign phase including facility programming, facility evaluation, and site planning.

The responsibilities of the client team during the predesign phase typically include input to and review of the various documents that will be included in the predesign phase report, including a facility evaluation, facility program, preliminary design alternatives, and preliminary construction cost estimates. The client team members derive their authority from and represent other individuals who are not within the client team, such as representatives from the users, administration, facilities, and finance.

The senior administrators' role is to assist in the identification of project goals, periodically review the progress of the predesign phase, and provide comments regarding the project's process as it relates to their expectations. This group may include representatives from the administration such as the president, provost, dean, and CEO; representatives from the business office such as the vice president, chief financial officer, and treasurer; and representatives from the development office. In addition to charting the project's course through the development of goals and periodically reviewing the project's direction, these individuals may review the various alternatives prepared by the client team and decide which alternative(s) should be selected for further consideration during the subsequent design/documentation phase. The selection of the alternative(s) will most likely include decisions regarding project size, program components, location, schedule, and cost.

Representatives from the users should provide detailed descriptions of the proposed facility through a series of interviews with the design professional. The user representatives should, therefore, be individuals who can describe the functional, area, utility, and environmental requirements of each space to be included in the project. They, in turn, obtain this information by direct consultation with the users, as discussed in the "Sociology" section of Chapter 1. These areas include research laboratories, laboratory support rooms (e.g., instrument and equipment rooms), shared support spaces (e.g., animal rooms, chemical storerooms, radiation laboratories), offices, and shared amenities (e.g., cafeteria, lounges, libraries). Information for other special areas, such as chemical stockrooms, supply storerooms, receiving, and custodial spaces, is also required. The users must, however, clearly understand that it may not be possible to accommodate all of their wishes in the final design and should be realistic in their requests.

If the project involves a renovation or an addition, EH&S personnel and representatives from the facilities/operation department should work with the design professional in developing a thorough description of the scope and conditions of existing facilities. The EH&S and facilities/operations representatives are responsible for (1) providing the design professional with previously completed studies and documents of the existing facilities (such as existing-conditions drawings), a description of the scope of required renovations, and a list of deferred maintenance items, and (2) reviewing and approving drafts of the facility evaluation prepared by the design professional.

If the project involves an addition or new building, representatives from the office or planning department responsible for overall campus/site planning activities, or a planning consultant previously engaged to complete a strategic or master plan, should assist in the selection of a site for the new construction. If a strategic or master plan has not been previously developed, the predesign services may need to be expanded to include this planning exercise so that the anticipated project can be coordinated with other potential projects in terms of siting, vehicular and pedestrian circulation, and utilities.

The responsibility of the design group is to work with the client group to produce the facility evaluation, facility program, preliminary design alternatives, and preliminary construction cost estimates that constitute the predesign report. If the client group includes a staff of design professionals, the design team should work actively with them throughout the project.

Primary Point of Contact

Throughout the predesign, design/documentation, and construction phases, a single individual should represent the client group and guide the process. This person is designated the project leader. On large projects this individual is typically the client team's project manager; for smaller projects, especially in smaller institutions, this person is often the user representative. The project leader works closely with the user representative and is often the liaison between the client team and the senior administrators as well as between the client team and the other members of the client group. He or she is responsible for the sustained progress of the project; serves as the primary point of contact for all communications between the client group, design group, and the construction group; and ideally attends all meetings scheduled to discuss existing facility evaluation, proposed facility program requirements, renovation scope, and/or new construction size and site. In other words, the project leader must be familiar with virtually every detail of the project and should be relieved, at least in part, of other responsibilities in order to allow sufficient time to perform his or her project-related responsibilities.

The design group should similarly be guided by a single individual who is responsible for all communications from the design group to the client team, including communications from consultants engaged by the design professional (e.g., structural, mechanical, electrical, plumbing engineers). These types of consultants will most likely be required to assist in the completion the facility evaluation (if required) and the facility program, both described later in this chapter. If the project entails new construction and a site has been selected through the completion of a strategic or master plan, the design professional leading the design group should be an architect. If the project entails an addition and/or renovation, an architect will most likely be required to lead the design group with or without the assistance of a laboratory programmer. Predesign phase participants and recommended communication paths are illustrated in Figure 2.2.

PRELIMINARY CONSIDERATIONS

Goals and Objectives

Goals and objectives should be established by the client with the assistance of the design professional at the beginning of the predesign process to define those aspects of the project that are important to the client. They should be developed in concert with any previously developed strategic or master plan, and reviewed periodically during the predesign process to determine if they require modification and to confirm that identified issues are being considered.

One technique used to establish goals is to identify attributes of a successful project. These may encompass issues related to collaborative research, interlaboratory interactions, shared instrumentation, flexibility, and adaptability. (Some of these attributes are more fully discussed in the "Sociology" section in Chapter 1.) Visits to recently completed projects often help in identifying both the features of a successful project and those to be avoided. However, unique attributes of the proposed research facility should also be identified and celebrated as defining characteristics.

Once the project goals have been identified, the objectives required to reach those goals need to be established. For example, if collaborative research has been identified as a goal, one objective would be to identify attributes of a laboratory facility that encourage collaboration. If interlaboratory interaction is identified as a goal, an objective may include the identification of features that promote such interaction.

Benchmarking

Benchmarking, which draws on information about other, similar research facilities, can be a useful tool for comparing existing and proposed facilities. It can be used to initiate the facility programming process or to evaluate the appropriateness of the completed facility program. Such information can be obtained from a variety of sources such as published projects and case studies, or directly from the university or private organization where the facility is located.

The direct use of benchmarking information may be difficult, however, for

BOX 2.1 Steps in Benchmarking

1. Identify similar research facilities.
2. Compare total area devoted to laboratories and support.
3. Compare size of laboratories, laboratory/laboratory support ratio, and area per principal investigator.
4. Compare laboratory renovation/construction costs.

several reasons. Benchmarking information may not be expressed in the same terms as the information developed for the existing or proposed research facilities (e.g., occupied area can be expressed either as net square feet (NSF), which may include corridors but not mechanical rooms, rest rooms, etc., or as net assignable square feet (NASF), which most likely excludes corridors and other unassignable areas). In addition, while the total building area is typically expressed in terms of gross square feet (GSF; all occupied and unoccupied areas including mechanical shafts and all wall thickness), the occupied area identified as the research facility may or may not include offices, conference rooms, or lounges, for example. If the benchmarking information includes costs, the cost figures for additions, renovations, and new buildings may be expressed as construction costs or project costs. (For a discussion of costs, see the "Research Laboratory Costs" section of Chapter 3.) Before benchmarking information is used, the basis of the information (e.g., NSF versus GSF, construction costs versus project costs, presence or absence of a central utility plant) should be confirmed to ascertain that the information is comparable to the information developed as part of the facility inventory. Possible steps in benchmarking are shown in Box 2.1.

If the basis of the benchmarking information can be established, the information should be used to compare similar research facilities. For instance, the size of the area typically allocated for synthetic chemistry laboratories may be substantially different from that allocated for physical chemistry and will most likely be very different from the size of the area allocated for biological chemistry research facilities.

Predesign Phase Report Elements

Facility Evaluation

If the proposed project is to include an addition to and/or renovation of an existing laboratory facility, the predesign phase should include an existing-conditions evaluation, which is needed to generate a description and preliminary cost estimate for renovations required to bring the facility up to current stan-

BOX 2.2 Steps in Conducting a Facility Inventory

1. Identify and categorize the spaces occupied by laboratory and laboratory support functions by
   a. type (laboratory, laboratory support, special support, offices, office support) and
   b. adjacencies (what laboratories and laboratory support functions are adjacent).
2. Identify the area occupied by various research groups.
3. Evaluate existing conditions for
   a Physical structure,
   b. Code compliance,
   c. Available services,
   d. Presence of hazardous materials,
   e. Site utility capacity, and
   f. Building systems capacity.

dards. If the proposed project is to include a new building, the predesign phase should include an inventory of existing research facilities. This inventory can be used to compare the proposed building specifications with the existing research facility's size, composition, and usage. An inventory of the existing facility would at a minimum provide a valuable database of the current uses and occupancy of existing research laboratories, laboratory support spaces, and offices. The existing-conditions evaluation should be completed by an architect with the assistance of consulting engineers, representatives from the facilities/operations department, and the research institution's EH&S office. To the extent possible, the project leader should monitor the progress of the inventory. See Box 2.2 for a list of possible steps in conducting a facility inventory.

Facility Program

The facility program is the document that describes the proposed project's area, function, laboratory components, laboratory services, and environmental requirements. It is developed from a series of interviews by the design professional with research facility users or their representative(s). The facility program can be a summary of space requirements or a detailed inventory. The summary is typically a list of space types, quantities, and space allocations. The detailed facility program usually includes a program summary supported by diagrams of space types and detailed data worksheets of function, anticipated activities, proposed fixed and movable laboratory furnishings and equipment, proposed laboratory services, and required environmental characteristics (e.g., temperature, relative humidity, lighting levels). The purpose of the diagrams is to provide a graphic representation of the area allocated for each space type; they should not necessarily be considered schematic designs of the space type. A detailed facility program generally provides sufficient information on which to base a preliminary construction cost estimate or planning exercise. Components of a facility program are given in Box 2.3.

Planning Alternatives

Planning alternatives should be developed after the requirements of the project are determined, should be based on the facility evaluation and program, and should take into account the sequence of construction or renovation activities. A number of preliminary planning alternatives should be developed, which

BOX 2.3 Facility Program Components

1. ***Facility program summary.*** A facility program summary is a list of the spaces to be included in the proposed new and/or renovated laboratory facility. This list could be an extrapolation of the list of existing spaces; however, it should reflect the users' needs rather than the current spaces occupied. Alternative types and arrangements of space, which may lead to more efficient space allocations, should be considered. In addition, the benefits of standardization of similar use areas should also be recognized. These advantages are more fully discussed in the "Design Considerations" section of Chapter 3.

2. ***Categorization of space by type***. The categorization of space by types (office, office support, laboratories, laboratory support, shared support, and so on) can aid in the calculation of total area requirements when area allocations are made for each space type. However, an alternative categorization may also be required when a suite comprising a collection of types of space is allocated to a particular research group.

3. ***Identification of appropriate standards to use in estimating total area requirements.*** Appropriate standards to use in estimating area requirements can be current area allocations, allocations determined as a result of benchmarking, or industry standards.

4. ***Determination of total area requirements.*** The net assignable square feet (NASF) equals the number of types of space multiplied by the area to be allocated for each type. This number will equal 50 percent to 70 percent of the gross square feet (GSF), depending on building type, size, and location.

5. ***Identification of desirable space attributes.*** Desirable space attributes include adjacencies, services, furnishings, and so on.

6. ***Identification of required space attributes.*** Required space attributes include temperature, humidity, lighting level, and so on.

BOX 2.4 Factors to Consider in Formulating Planning Alternatives

- Ways to satisfy facility program
- Magnitude of research disruptions caused by relocations
- Necessary code-related upgrades
- Site analysis
- Need for temporary facilities ("surge space")

may be used to explore the advantages and disadvantages of various design alternatives, and a single recommended alternative should be identified. Factors to consider in formulating alternatives are given in Box 2.4, and examples of planning alternatives are presented in the "Design Considerations" section of Chapter 3.

For renovations the description of the alternatives typically includes a combination of text and preliminary drawings that illustrate the relative locations of facility program elements within the context of the existing facilities. For additions or new construction the preliminary drawings typically include a site plan illustrating the approximate size and location of the proposed facility in relation to existing buildings, roads, paths, utilities, and other site features.

Preliminary Cost Estimates

The description and proposed phasing for each planning alternative are used in conjunction with the facility program to generate preliminary construction cost estimates for each alternative. If a complete facility program was not used as the basis of the planning alternatives, information such as construction characteristics, fixed and movable laboratory equipment, laboratory services, mechanical, electrical, plumbing systems and equipment, and site development and utilities may be needed to generate the preliminary construction cost estimate. At this point, a client's construction manager or professional cost estimator should be engaged to independently derive a preliminary construction cost estimate. In addition, construction costs for the proposed project should be compared with other similar projects in the client's area of the country. See the section on "Research Laboratory Costs" of Chapter 3 for a more complete discussion of costs.

The preliminary construction costs can be used to estimate the overall project costs. As discussed in the costs section of Chapter 3, construction costs typically represent 65 percent to 75 percent of the total project costs. Hence an itemized project budget should be developed to accurately estimate the costs over and above the construction costs. The design professional can assist in the development of a template of these potential nonconstruction costs but, again, an independent cost estimator should also be engaged. If the budget is predetermined, the estimated project budget—and the actual work to be done—may have to be adjusted.

Application of Predesign Phase Report

Build versus Renovate

One purpose of developing planning alternatives is to help decide whether to build a new or renovate an existing research facility. Evaluation of the planning alternatives should consider all of the issues related to a complex research laboratory project and should quantify the issues in terms of time and money. The project schedule and cost estimates should therefore include all phases of renovation, relocation, new construction, and cost escalation, as well as an assessment of the remaining useful lifetime of the building. Following the evaluation of the planning alternatives, it is not uncommon to discover that the costs of a complex renovation project involving significant relocations over a long period of time may approximate the costs associated with construction of a new facility. Beyond the often substantial renovation costs, the decision to build versus renovate is often influenced by the resulting functionality of the renovated facility. For example, the organization of the renovated spaces may be suboptimal because of efforts to minimize disruptive relocations during construction, or because the renovated spaces may lack optimal adjacencies. For a more complete discussion of this topic, see the "Research Laboratory Costs" section of Chapter 3.

Recommending a Preferred Alternative

Before recommending a preferred planning alternative, the advantages and disadvantages of each alternative should be compared by the client team and the senior administrators. This comparison may include the amount of occupant disruption, spatial organization of the completed project, construction schedule, construction costs, and other related factors. The comparison of the planning alternatives should also identify the degree to which each alternative achieves the original project goals. The recommendation of an alternative is based on an assessment of the advantages and disadvantages of each alternative. The recommended alternative can be used as the basis of the subsequent design/documentation phase.

DESIGN AND DOCUMENTATION PHASE

The formal design and documentation phase follows the predesign phase and includes the design of the research facility and the completion of documents needed to begin construction. The design and documentation phase is further divided into subphases often referred to as the schematic design, design development, construction documents, and bidding phases, although some state and federal agencies may use different terminology. The design of the facility is developed starting with general directions and working toward specific details in the schematic design and design development phases. Global decisions regarding the relationship of laboratories and offices should be made during the schematic design phase. Specific questions regarding laboratory bench details are most appropriately discussed during the design development phase. The documents required to construct or renovate the laboratory facility are completed in the construction document phase. Thus construction details, such as those related to exterior wall and lab cabinet construction, are best discussed in the construction document phase. The design and documentation process can be expedited by following this natural order. This means that design decisions have to be made before the construction documents are created. The bidding and construction phases commence following the review and approval of the construction documents.

Although much of the work in these phases is conducted by the design group—the design professionals including architects, laboratory planners, engineers, specialty consultants such as fire specialists, environmental consultants, and code consultants—involvement of the client group is essential. If a construction manager has been engaged prior to the completion of the construction documents, the involvement of the construction group is also essential. The necessary participants and the recommended communication paths are illustrated in Figure 2.3. The types of decisions to be made and approvals required should follow the general-to-specific order outlined above. The decision-making process and lines of communication established in the predesign phase should continue seamlessly through the subsequent phases of the project, as should the single point of contact for the client and design teams. One new procedural element must be established—a rigorous review process to verify the accuracy, completeness, and constructibility of all design documents.

Procedural Guidelines

The procedural guidelines used during the design and documentation phases are similar to those used in the predesign phase. Many of the same groups, teams, and individuals are still engaged, and the decision-making process is still in effect. However, the frequency of the design group's formal meetings with and presentations to the client team differs throughout the design and documentation phases: such meetings and presentations are frequent in the schematic design phase, less frequent in the design development phase, and periodic in the construction document phase. The involvement of the client team, by contrast, increases throughout the design and documentation phases because of the quantity and specificity of the design and construction documents that need to be thoroughly reviewed prior to their approval.

Participants

If the recommended predesign phase has not been conducted, it is essential that the client group, especially the users through the user representative and client team, provide detailed descriptions of the desired facility in the schematic design phase. As discussed in the "Sociology" section in Chapter 1, direct input from the users is essential. If the project involves a renovation or an addition, representatives from the facilities/operation department and from EH&S should work with the architects and engineers to develop a description of the scope and conditions of the existing facilities.

Even when a complete predesign phase has been conducted, the users (through the client team) and the EH&S representative should ensure that the desired details of the project are being met, especially in the schematic design phase. Other individuals, such as those empowered with decision-making authority, should review the progress of the design documents. Occasionally representatives from the trustees or scientific board of advisors may also be involved with the review procedures at critical points of the process to resolve issues regarding project scope and further definition of project aesthetics.

Process

It should be recognized that all formal drawings are communication and should be treated as such. The importance of establishing a rigorous process to verify their accuracy and completeness cannot be overemphasized. Complete and accurate communications—within the client group, between the client and design groups, within the design group, and between the design and construction groups—are absolute requirements for an efficient design process and the production of accurate and complete construction documents. Beyond communication, the formal drawings and specifications are also the documents on which the construction bids are based. Because, by statute, many institutions are required to accept the low bidder, it is absolutely necessary that every requirement of the project be unambiguously detailed.

Several methods can be used to verify design and construction documents. Typically, the design group provides the client team with drawings and specifications at the conclusions of the schematic design and design development phases. Drawings and specifications are also provided at various times during the construction document phase. These progress documents represent a particular percentage of completion, often 50 percent, 75 percent, and 100 percent. Regardless of the verification procedures used, the client team is responsible for carefully checking all documents for adherence to the facility requirements at several stages during the design and construction phases. Each user is responsible for verifying the design of his or her specially designated spaces. The client team should confirm that the university or private company has the expertise to execute this responsibility. If not, it is in their interest to engage an individual with experience in architectural and engineering reviews to perform this function.

Necessary changes identified in the design and construction documents by the client team should be indicated in such a manner that they can be clearly identified by the design professional. The annotated design and construction documents should then be returned to the design group, with the client team retaining a copy to facilitate future verification that the desired changes or corrections have been made. For facilities with mandatory low-bid contract restrictions it is essential to engage an independent architect/ engineer to verify that the construction documents are complete, coordinated, and technically appropriate to build the desired facility.

Design and Documentation

Schematic Design

During the schematic design phase, the architect, in consultation with the users through the user representative or client's project manager, investigates various aspects of the design. These include large- to small-scale issues including the overall size, shape, and general appearance of the new building or renovation, alternative organizations of the spaces within the building, and the general configuration of the elements within the spaces. (Various aspects of the laboratory design are discussed in the "Design Considerations" section of Chapter 3.) The formal definition of the schematic design phase is given in Box 2.5. If a thorough predesign process has been completed, the schematic design phase can proceed unimpeded because the project scope will already have been generally established.

Large-scale issues concerning design concepts for the facade and the overall shape and size of the new facility may be explored in the schematic design phase. For renovations, this effort may focus on alternative design concepts for public corridors and lobbies.

Intermediate-scale issues concern the configuration of the overall laboratory facility and the organization of space on each floor. These issues include the vertical (between-floors) and horizontal (same-floor) relationships of offices, research laboratories, and research laboratory support spaces. Laboratory support spaces include shared instrument rooms and equipment spaces. These issues also may include the relationship of laboratory and nonlaboratory facilities such as lounges, libraries, conference rooms, and other interaction areas as well as the configuration of individual spaces within the laboratory facility.

BOX 2.5 Schematic Design Phase

Schematic design establishes the general scope, conceptual design, and scale and relationships among the components of the project. The primary objective is to arrive at a clearly defined, feasible concept and to present it in a form that achieves client understanding and acceptance. The secondary objective is to clarify the project's program, explore the most promising alternative design solutions, and provide a reasonable basis for analyzing the cost of the project.

Source: Excerpted from American Institute of Architects (1993), p. 638.

The relationships between elements affect construction and operational costs of the facility as well as sociological concerns such as ease of collaboration. For instance, the grouping of similar space types such as research laboratories horizontally or vertically has the cost benefit of localizing the special mechanical, electrical, and plumbing services that are typically required. However, this type of organization may isolate offices, lounges, and other nonlaboratory areas to more distant parts of the floor and/or building, whereas locating offices adjacent to research laboratories may provide a greater number of potential opportunities for researcher interaction. Likewise, the number and area of floor plates will determine the optimum configuration of the facility when existing site constraints are considered. The number and area of laboratory floors will dictate the number of research groups that can be accommodated in a given area. Proximity of research groups will, in turn, affect the possible interactions, collaborations, and shared facilities between different research groups. (The sociological implications of these choices are discussed in Chapter 1.) Because the configuration and arrangement of spaces affect the functionality, efficiency, and potential for and type of interaction, choices to be made among alternatives must reflect the needs and interests of the user and the organization.

Small-scale issues include the configuration of individual spaces within the laboratory facility as well as the arrangement of elements—laboratory benches, fume hoods, desks, and other large pieces of equipment and storage units—within those spaces. Modular design, which uses a similar dimensional module for various space types, and generic laboratory planning, which uses a similar arrangement of the elements contained within each individual space, are the preferred methods for new laboratory construction. The modular and generic approach to laboratory planning can also be used for renovations, but the existing building structure may limit the degree to which a modular approach can be used. A modular design approach allows for the development of alternative organizations and ensures a degree of flexibility, should the need for alternative arrangements of spaces become necessary during the design/documentation and construction phases. A modular approach can also facilitate subsequent renovations. The use of generic laboratory planning can meet customization in the laboratory or in the laboratory support rooms to accommodate individual research requirements. When research facilities are constructed or renovated with modular design and generic laboratories, construction costs tend to be lower and construction activities tend to proceed more rapidly. Once occupied, laboratories can be reassigned with minimal retrofit costs.

The products of the schematic design phase typically include architectural drawings such as a site plan, floor plans for all new or renovated floors, exterior elevations (for new facilities), and building sections (to explain floor-to-floor heights). For research laboratory projects, the schematic design floor plans are used to finalize the organization of laboratories, laboratory support spaces, and offices. The drawings may also include larger-scale floor plans of the laboratories and laboratory support spaces to begin to illustrate some of the design details. Structural, mechanical, electrical, plumbing, and fire-protection drawings showing the general organization of systems and equipment are also provided. These drawings may include single-line plan representations of the various elements and systems coordinated with the laboratory floor plans and sections. Mechanical rooms housing the major equipment should be drawn at a larger scale to confirm that adequate space has been allocated for the mechanical, electrical, plumbing, and fire-protection equipment. Other materials such as perspective renderings, three-dimensional models, and computer simulations may be produced as part of the schematic design phase. An outline specification is also typically provided; it describes the quality of materials and other technical details (in outline format) of the building materials systems and equipment. All of these documents are used to generate or update the preliminary construction cost estimate. As described in the procedural guidelines, all such drawings should be verified by the client team—particularly the users—to ensure that the design group correctly understands the program requirements.

Design Development

In the design development phase, the design group develops a detailed plan for all interior and exterior elements. Other participants involved in this phase include the client group. Because the goal of the design development phase is to finalize all design details (a formal definition of the design development phase is provided in Box 2.6), including the aesthetic elements of the architecture, the design group—particularly the architect—must understand the expectations for the facility and, in turn, communicate to the research institution's participants how his/her efforts will meet their needs.

During this phase, the design of all structural, mechanical, electrical, plumbing, and fire-protection systems and equipment is finalized. Many design professionals recommend that large-scale coordination drawings be completed to confirm that all such systems and related equipment are fully coordinated with

BOX 2.6 Design Development Phase

The primary purpose of design development is to further define and describe all important aspects of the project so that what remains is the formal documentation step of construction contract documents.

Source: Excerpted from American Institute of Architects (1993), p. 643.

all structural and architectural elements. The coordination of these systems is a critical part of the design and documentation process for laboratory construction or renovation, and the foundation for this coordination is established during the design development phase. Any drawings developed should be verified for code compliance as well as for accuracy by the appropriate specialty consultants.

Interior elevations, which give two-dimensional views of the laboratory interiors, including laboratory benches and fume hoods, and typical wall sections are often part of the design development drawings. They are used to confirm that the programmatic requirements to be met by the laboratory's components are accurately and comprehensively documented, and they provide the basis for an updated construction cost estimate as well as for the construction documents.

Related documents, such as specifications that describe all aspects of the research facility design, are also provided at this stage. These documents, based on the outline of specifications prepared for the schematic design phase, include additional information such as specific products and manufacturers and may be used to update previous estimates of construction costs. Depending on the outcome of the cost estimate, revision of the project's scope and details may be needed to meet the construction budget.

To aid in necessary communication within the client group, the architect should consider supplementing conventional pictorial documents, such as floor plans, elevations, and sections, with others that may be more meaningful to the client. These include perspective drawings, three-dimensional computer-aided design (CAD) drawings, axonometric drawings (two-dimensional drawings that depict three-dimensional objects), study models of both interior and exterior design elements, and full-size mock-ups of interior and exterior elements, made of either paper and cardboard or the proposed building materials. Construction of a full-size mock-up of the proposed laboratory module, permitting users to evaluate the proposed design prior to committing to the design and construction of several laboratories of a similar design, is highly recommended, particularly prior to the commencement of construction documents.

The client team must make the effort to understand the general and specific aspects of the design, the user representative should actively participate in the development of design elements, and the client's senior administrators should approve the general form of design early in the design development phase. The members of the client group, including the client's special consultants, EH&S representative, and representatives of the organizations facilities/operation department, should also be involved. Again, the client team should carry out timely and rigorous design verification of all documents developed during this phase. Each user is responsible for verifying the design of his or her specially designated spaces.

Construction Documents

During the construction documents phase, the design group completes the documents required by the contractor to build or renovate the laboratory facilities. With a few exceptions all documentation completed prior to this phase is used to help establish the scope and design of the research facility and communicate them to the client team and client group. Based on the previously completed design development drawings, the construction documents incorporate any revisions required as a result of the design verification process and any adjustments to the scope of the project. Box 2.7 indicates the scope and purpose of these documents.

If all design decisions were made and all design approvals were obtained during the design development phase, then the architect and engineers can focus on developing construction documents that are consistent with the previously approved design documents. However, research laboratory facility projects require a substantial amount of coordination among the various project components, including architectural, structural, mechanical, electrical, plumbing, and fire protection systems and equipment. Because laboratory constructions or renovations typically involve many more details than do other building projects, the construction documents phase requires continued contact and interaction with

BOX 2.7 Construction Documents Phase

- Construction documents communicate to the client, in detail, what the project involves.
- They establish the contractual obligations of the client and the contractor during the project, and they describe the responsibilities of the architect or any other party administering or managing construction contracts for the owner.
- They may be the basis for obtaining regulatory and financial approvals needed to proceed with construction.
- They communicate the quantities, qualities, and configuration of the work required to construct the project. The contractor, in turn, uses the documents to solicit bids or quotations from subcontractors and suppliers.

Source: Excerpted from American Institute of Architects (1993), p. 703.

the client team. It may be in the client's interest to have the construction documents independently verified for accuracy and completeness.

In addition to indicating all components that will be provided and installed by the contractor, the construction documents should also indicate all items that will be provided by others but that will require coordination with services or with components to be installed by the contractor. The client or a subcontractor engaged by the client may provide these items, often referred to as not-in-contract (NIC) items, which may include laboratory equipment that must be coordinated with laboratory services or large furnishings that must be fit in with built-in components.

Large-scale coordination drawings, begun during the design development phase, are completed to confirm that all mechanical, electrical, plumbing, and fire protection systems and equipment are fully coordinated with all structural and architectural elements. The importance of coordinating these systems cannot be overemphasized as a critical part of the design and documentation process for laboratory construction or renovation projects. In a study of construction change orders, the Veterans Administration found that failure to ensure such coordination was a frequent reason for change orders.[1]

The completed construction documents, comprising drawings and specifications, are combined with other contractual documents, such as contract forms, to serve as the basis for a contract between the client and contractors, as well as to develop bidding forms and requirements. The construction documents are used during the bidding phase to obtain competitive bids for the project and during the construction phase to define the responsibilities of the construction, client, and design groups.

CONSTRUCTION PHASE

This section considers the selection of a contractor, the identities and roles of the active participants, the process of their interactions, and the special issues that need attention. The participants and their interactions are illustrated in Figure 2.4. An important point of this phase of the project is that the construction documentation for the laboratory facility may require clarification, and so the input and evaluation offered by the construction phase team often determines the final quality of the project. A specific procedure must also be developed to handle evolving user needs and desires and construction document omissions and errors, in order to minimize change orders and keep the construction project on schedule and on budget. Finally, it is important to note that the potential for substantial liability commences with the start of construction activities. There-

[1]Reported to the committee by Leo Phelan, Veterans Administration, April 13, 1998.

fore, the procedures developed to enhance and regulate communication must continue to be rigorous and must be rigorously adhered to.

Procedural Guidelines

Contracting Considerations

The lowest cost for the kind of construction project described in this report—the design and build delivery model—is usually obtained through competitive bidding. Ideally, the general contractors who submit bids will be prequalified, although state and federal agencies may not allow the prequalification of general contractors. Selecting the contractor is discussed below in the section on "Selection of a Contractor."

For projects that require an accelerated construction schedule, the "early packages" project delivery model can be used. In this model, certain portions of the construction documents, such as for excavation, foundations, and structural steel or concrete, can be completed and issued to subcontractors for competitive bidding prior to the completion of the full set of construction documents. Construction activities can thus begin while the construction documents for interior and other less critical elements are completed. A general contractor or construction manager should be engaged by the client to manage the bid process and engage the subcontractors for these early packages. To limit the client's risk, the general contractor or construction manager may agree to a guaranteed maximum price for the project prior to engaging subcontractors. When the remaining portions of the construction documents have been completed, they too can be issued to the appropriate subcontractors for competitive bidding. This model has the advantage of accelerating the construction schedule and maintaining a degree of bid competition.

Selection of a Contractor

The client needs to decide which type of construction contract and contracting method to use. The two general types are formal and negotiated (some consider the negotiated type to be more informal). The formal method generally requires an advertisement, followed by review/prequalification, bidding/negotiation, and award. The negotiated contract, which can also start with an advertisement and a review/prequalification process, is often used with a contractor or construction manager known to the client or architect/engineer, or recognized by the industry. Following completion of the construction documents, the contractor or construction manager may obtain competitive bids on the various project components. Details of alternate contracting methods are discussed in the chapter titled "Delivery Options" in *The Architect's Handbook of Professional Practices* (AIA, 1993).

As in all phases of a laboratory construction or renovation project, good communications are essential in the selection of a contractor. A thorough prebid briefing and tour of the site or the building to be renovated should be provided, as should an adequate period for the review of bid documents and preparation of the contractor's bid. A timely and effective way to respond to contractors' questions should be implemented and should include answers and supplemental information, or addenda, distributed to all bidders.

Participants and Participants' Responsibilities

The construction team should include, at a minimum, the participants listed in the "Construction" column of Table 1.1, Chapter 1. The recommended communication paths among the participants are illustrated in Figure 2.4.

Client Group. As in the predesign and design/documentation phases, one member of the client team should be appointed the primary point of contact for all communications within the client group and among the client, design, and construction groups. For most projects, this person is the client team project manager.

The senior administrator, typically the person ultimately responsible for space allocation in a facility, should be an active participant in the construction phase for administrative oversight. The senior financial officer of the institution should be periodically briefed by the client budget authority and might sometimes need to make a final decision on a change from the original design that has significant financial implications.

The user representative brings users' issues to the attention of the construction-phase team and reports regularly to the senior administrator about the progress being made in the construction phase.

One member of the client group should act as the internal construction administrator, providing technical oversight for the client. Usually this person is either the client project manager or the representative of the design/construction unit of the facilities/operation department. The advantage of appointing the client project manager as the construction administrator for the client is that this person is continuously involved in the project from predesign through postconstruction. The construction administrator should have experience in supervising construction projects at the institution. If the institution does not have an appropriate person, then a construction administrator may be hired from the outside.

The client, through the project manager, is responsible for activity coordination, contract enforcement, stopping work, provision of funds to cover the cost of all contracts, and management of the project. The project manager may also verify the appropriateness and cause of each change order or engage an independent entity to do so.

Design Group. The design group has a single point of contact who serves as the architect's construction administrator. Usually this person is the architect's project manager. This individual is responsible for ensuring that clarification and interpretation of construction documents are obtained from the design professional and engineers and communicated to the contractor; seeking approval from the client team for all changes in the scope of work; and, depending on contractual arrangements, reviewing and approving operation and maintenance manuals and "as-built" documentation prepared by the contractor. The construction administrator also assists the client team and construction manager in seeking rights-of-way or permits required prior to the start of construction or renovation and perhaps also in obtaining occupancy permits.

The design group includes representatives of the engineers who will provide technical oversight of the construction. These individuals visit the construction site periodically to assess progress and to ensure that construction meets the design intent and that the equipment and materials meet specifications. The frequency of site visits varies depending on the architects and the engineers involved and also varies over the course of the construction activities. During the most active periods, the architect's representative may visit the site weekly or biweekly. These individuals also check shop drawings from vendors and subcontractors, issue responses to requests for information from contractors, and make recommendations to the design professional regarding change orders.

Construction Group. The construction group, which typically includes the general contractor and/or construction manager and subcontractors, is the most heterogeneous of the three participant groups involved in the construction phase of a laboratory construction or renovation project. The general contractor/construction manager is responsible for the construction schedule, quality, methods, materials, direction of labor, and job safety and site security; for seeking construction permits and assisting the client team in obtaining occupancy permits; and for start-up activities and providing the client group assurance the facility can be occupied.

The contractor/construction manager should employ experienced construction supervisors to manage the work force and the delivery of materials to the site. Subcontractors typically also employ supervisors to direct the work of their tradespeople, and these supervisors communicate with and are responsible to the general contractor. The general contractor's supervisor attends regular project meetings with the project managers from the client team and design group. Construction administrators representing the client team and the design group may also attend and report on the progress of the work and help resolve conflicts between construction participants. The general contractor's supervisor also issues requests to the design group for information, manages the shop drawing distribution, provides estimates for change orders, and approves applications for payment to the general contractor.

Partnering

Because of the large number of participants involved in the construction phase of the project, the development of procedures for complete and accurate communication between them is essential. One method that has been successful is partnering, which brings together key stakeholders (client/users, architects, engineers, suppliers, construction manager, contractor, and subcontractors) to work as a team. The users should be included because they are far more knowledgeable about the program and equipment than are the other partners in the project, and this is critical to a successful laboratory construction or renovation project. However, the users' input should be communicated through the user representative to ensure that the scope of the project is maintained and the number and cost of change orders minimized. The partnering process provides a way to mutually agree on a formal strategy of communications and problem solving, and thus creates an environment of trust in which the team members communicate with one another and work together to achieve common goals.

Process Control

Decision making and problem solving in the midst of evolving users' needs and desires, budget and space constraints, and omissions or errors in the construction document are often complicated and sometimes contentious. Thus, even with the proper team composition, the process of managing the project from final design to inspection, move-in, and postoccupancy evaluation is critically important.

Scheduling and Developing a Format for Regular Meetings

The dates for regular meetings of the construction phase group should be established at the beginning of the construction phase, and a mechanism for calling ad hoc meetings, when necessary, should be established. The client's project manager typically establishes the meeting agenda. The meetings should be attended regularly by the client project manager, the architectural and engineering project manager, the construction administrator, the general contractor's supervisor, the EH&S representative, and other experts as needed.

Establishment of Construction Phase Milestones

Construction phase milestones should be established as early as possible in the construction phase. A suggested set is given in Box 2.8.

Construction Progress Review

The project managers representing the client and design groups should visit

BOX 2.8 Construction Phase Milestones

- Contract negotiations are completed.
- Contract is awarded and start date is issued.
- General contractor issues contracts to subcontractors (site work, foundations, framing, mechanical, electrical, finishes, etc.).
- General contractor submits shop drawings and equipment specifications for review.
- Major components are acquired (allowing lead time for HVAC components, etc.).
- Interim traffic (auto and pedestrian) patterns and controls are developed, to include parking.
- Site work begins.
- Construction site requirements (materials, equipment, staging areas) are established.
- Foundations are laid.
- Shell construction or infrastructure is built.
- Fit out or finishes are done.
- Punch-list is completed.

the construction site periodically (two to four times per month) to assess the project's progress and to see if the construction meets the design intent and the equipment and materials meet specifications. The individuals representing the design group's engineers typically visit the project site less frequently over the duration of the project but should visit the site as required to review the progress of their respective disciplines. These individuals also check shop drawings from vendors and subcontractors, issue responses to requests for information from contractors, recommend approval or rejection of change orders to the client, and approve applications for payment to the general or prime contractor. It is essential that the shop drawings submitted by the vendors and subcontractors be thoroughly reviewed both by the general contractor and by construction administrators representing the client and design groups. A large fraction of change orders are necessitated by problems arising from inconsistencies between the subcontractor shop drawings and the construction documents.

It is important to obtain continuous review of the construction through the eyes of the users, who communicate with the design group through the user representative. The users generally understand only their specific needs, while the user representative has the perspective of the resources and constraints of the entire project.

Project Pitfalls

"On time" and "on budget" are the two key terms for a successful project.

Since time and budget are generally related, it is important to keep the project moving forward at the planned (contracted) pace. Two major pitfalls of laboratory projects are changes in scope of the project and upsets to the schedule. Changes in scope are often user driven and reflect inadequate communication during the predesign, design, and documentation phases. However, changes in scope are justified in certain situations, such as those resulting from the change of proposed users during the construction phase. Changes in the project scope may also be justified if there is a prolonged hiatus between the completion of the predesign, design, and documentation phases and the commencement of the construction phase. If these changes are small and occur late in the project, it may be more cost-effective to complete the project and then contract for a minor renovation, rather than delay the construction of the entire project and incur all the costs associated with both the delay and the change.

Schedule delays may originate from a variety of sources including overly aggressive scheduling by the general contractor, delays in the review and approval of shop drawings, or lack of project funding. Though some delays are unavoidable due to weather, work stoppages caused by subcontractor/contact renegotiations, and labor problems unrelated to the project, many delays result from an inexperienced contractor or a lack of communication between the client, design, and contractor groups. Whatever their cause, schedule delays generally translate into cost overruns.

Implementing previously developed cost reduction design alternatives can offset cost overruns created by unforeseen events. These alternatives should ideally be developed during the construction document phase to provide some degree of flexibility should the general contractor bids exceed the established budget or should cost overruns be created by unforeseen conditions. If cost reduction design alternatives were not identified before the bidding phase, they will most likely have to be developed as the project continues. The advantage of design alternatives is that they represent discrete costs and can be used as tradeoffs in the context of the budget and future use of the facility.

Change Orders

It is extremely difficult to produce construction documents that do not require clarifications or supplementary information. Occasionally these clarifications may result in modifications to planned or previously completed construction. Changes may also be required because of unforeseen site conditions, program changes resulting from research or organizational changes, drawings that are not sufficiently coordinated, the specifying of materials that are no longer produced, and equipment that does not fit. A process that encourages open communications to cope with these changes must be established and implemented. One of the primary reasons to schedule construction meetings on a frequent basis is to provide a forum for frequent communication among the project man-

BOX 2.9 Special Laboratory Facility-Related Issues

1. Involvement of the EH&S representative in the project team must be continuous, especially in decision making for chemical venting, disposal, and worker safety issues.
2. Community relations must be continuous during the project.
3. A decision process for change orders is more important with laboratory facilities than other construction/renovation because of the complexity and the variability of requirements for laboratories in the same building.
4. Users' input is important but must be modulated because of the complexity of the project and the interrelations among the different parts of it.

agers of the client, design, and construction groups. Frequent meetings and well-established communication networks will help reach the goal of the construction phase team to complete the project within budget, on time, at the specified quality, and without litigation. Change order control is also discussed in the "Research Laboratory Costs" section of Chapter 3.

Tradeoffs between budget, schedule, and changes in scope are inevitable with laboratory facilities. It is important that a process be developed at the beginning for dealing with these questions within the project team.

Special Issues Related to Laboratory Facilities

In addition to the participant, procedure, and process control issues discussed above, which are common to most construction projects, laboratory facilities have several issues specific to them. These are listed in Box 2.9.

POSTCONSTRUCTION PHASE

The postconstruction phase is typically used to confirm that the performance of the recently completed research facility is consistent with the construction documents and the expectations of the client group. Also during this phase the client group is familiarized, in a process called building commissioning, with the procedures required to operate and maintain the research facility. Just as decisions made during the predesign, design/documentation, and construction phases affect building performance and use for the life of the facility, the building commissioning phase of the process, in which the client verifies that the building was built and will operate as planned, also starts in the predesign and design phases. But the client's commitment to the operation and maintenance of the facility for the foreseeable future should be fully discussed and finalized during this final phase of the project.

This phase differs from the others in the project in that some of its processes overlap the earlier predesign, design and documentation, and construction phases. It also differs in that it continues after the project is completed and some of the previous participants are no longer required. This section will discuss the operations that constitute the postconstruction phase of a project, indicate when those take place during the building project, and describe those that continue long after the project is completed.

Building Commissioning

Building commissioning is often thought of as a postconstruction program, because in this phase the building is inspected to ensure that it was built as planned and will operate as planned. However, building commissioning is really a process that provides the client with assurance that the building has been programmed, designed, constructed, and put into service according to the client's expectations. There are several different aspects of building commissioning; they include opportunities for operations and management input into final design decisions, system verification, the provision of operations and maintenance manuals, and the production of "as-builts."

During the design phase, the building commissioning process provides the group that will operate the building systems—usually the operations and management department—and the facilities management department, an opportunity to recommend the systems they will maintain. The recommended process is a formal review of the facility designs, prior to final design, by the client's organization that will operate and maintain the facility. This ensures a seamless operation from the completion of the building project, through the start-up and testing of systems, to the users moving in and operating the building.

During construction, inspectors representing the client and officials representing the community (code inspectors) will monitor the construction process. Some system—such as water and gas, HVAC (both supply and exhaust), control, and others—will be tested upon partial or entire completion. In some cases the code inspectors will certify the systems before they can be put into operation; in other cases the contractor certifies that the systems operate as designed. Occupancy of a new laboratory facility should not occur until the engineering systems designed to safeguard occupants against harm have been tested and verified to be operating properly. Such systems include fire communication, alarm, and suppression systems; laboratory chemical hood ventilation systems; eyewash fountains and emergency showers; and ventilation systems supporting controlled access areas. Validation of these systems should be performed as part of a formal commissioning program that begins prior to or immediately following completion of the construction phase of the project. The EH&S professional assigned to the client team should oversee validation procedures that involve health and safety engineering systems. The project team should also consider developing an orientation program to inform users about how the laboratory facility was designed to support safe use and how the occupants can work safely within their new facility. This task could be delegated to the client's EH&S representative.

Operation and maintenance manuals, which are required regardless of the implementation of a building commissioning process, are often more comprehensively prepared and reviewed during this phase of the project. Although they are often overlooked during the course of a project, these manuals are critical for the owner because they provide information about the operations and maintenance of all systems and equipment. They may include videos as well as print copy, but there is a current initiative by the National Institute of Building Sciences to standardize this information. The provision of operation and maintenance manuals should be included in the designer's contract.

Throughout the construction, the general contractor maintains a set of construction documents on which are recorded all changes made during construction. This information should be reflected on the original drawings and specifications and provided to the owner in the form of hard copies and, more recently, in electronic format. The design group should be engaged to review and verify these. These drawings, often called "as-built" drawings, provide the owner with an accurate record of the completed project.

The client's facility personnel will use the as-built drawings and the operations and maintenance manuals on a daily basis, and so the client should put in place a process for updating these for the life of the facility.

And, finally, during building commissioning staff that will operate and maintain the facility must be trained on specific systems. This is critical for buildings with highly technical systems. Training may be provided through equipment service contracts that include provisions for training of the owner's staff.

Postoccupancy Evaluation

In addition to confirmation that the building was built and is operating as planned, the client also requires assurances that the building will continue to operate as planned. The process of surveying and analyzing recently completed and occupied facilities is called "postoccupancy evaluation" (POE) and is usually done after the first year of operation. This review allows the client and others involved with the project to determine how the building is performing and how to improve the overall facility program. The goals of POEs are listed in Box 2.10.

POEs are usually conducted by a survey team of representatives from the client, design, and construction groups and may also include professional staff and outside experts from each design discipline including architectural, civil/structural, mechanical, and electrical, as illustrated in Figure 2.5. Each technical professional involved in the review process should evaluate their respective major system (for example, electrical engineer for emergency power) and its effec-

BOX 2.10 Goals of Postoccupancy Evaluations

1. Review problems associated with standards used for development of facility program requirements.
2. Review problems associated with construction, building commissioning, and operations.
3. Evaluate the entire planning, design, construction, and operation process.
4. Identify cost increases during design and construction by reviewing contract documents, change orders, and as-built drawings.
5. Evaluate staffing patterns and their adequacy.

tive performance for the facility. The team should visit the facility and inspect all exterior and interior elements of the facility and site. The survey report should discuss the use of alternate materials and/or systems (i.e., those not called for in the original specifications), and comment on the cost-effectiveness of the installed systems. During the visit, survey team members should interview the facility managers and occupants to determine their reactions to the building. In conducting the survey, the team should not limit their observations to design or construction deficiencies, but should also note facility features, efficient operation, maintenance, and design elements pleasing to the occupants and to visitors.

Postconstruction Interactions

When a construction or renovation project is completed and commissioned, the owner's responsibility for communication does not end. It will shift, however, into a new arena. Users and others within the institution will clearly maintain contact with the administration, and there may be some need for further contact with design and construction experts if problems are discovered at a later time. But the most important—and often overlooked—area of communication to be addressed is the interaction with the laboratory's neighbors. These issues are discussed in the NRC report *Prudent Practices in the Laboratory: Handling and Disposal of Chemicals*, which addresses a variety of such interactions, ranging from the need for contact and joint planning with emergency response teams to the need for public notification and outreach.

Financial Responsibilities of Ownership

The financial responsibilities of ownership commence before the laboratory renovation or construction is initiated and continue after it has been completed; they run from the selection of building materials and methods through its continued maintenance and repair. To neglect any of these is to trivialize the effort that has gone into the project.

Life-Cycle Approach to Building Costs

The life-cycle approach to building costs is best expressed in the executive summary of the 1991 NRC report *Pay Now or Pay Later: Controlling Costs of Ownership from Design Throughout the Service Life of Public Buildings* (NRC, 1991, p. xi).

> A building is an investment made by owners in anticipation of the shelter and services it will provide to the people and activities it will house. With proper management of this investment, returns may continue for hundreds of years, but failure to recognize the continuing costs of ownership can lead to premature loss of services and deterioration of the building and high costs for the building's users. Some materials and building systems are particularly reliable or durable and repay their higher initial costs with savings in future operating and maintenance efforts. Other materials or systems may be selected because their lower initial costs meet the limits of available construction budgets and, with proper use, are likely to deliver entirely satisfactory service. Sometimes safety, security, or aesthetic concerns warrant both higher initial and future costs. Designers and owners of buildings recognize that there are many such choices and trade-offs among initial construction costs, recurring operations and maintenance (O&M) costs, and building performance. Decisions about a building's design, construction, operation, and maintenance can, in principle, be made such that the building performs well over its entire *life cycle* and the total costs incurred over this life cycle are minimized.

For further discussion of this topic, see the "Research Laboratory Costs" section in Chapter 3.

Committing to the Cost of Ownership

Owners must bear the responsibility of being good stewards of buildings. Underfunding of maintenance programs for facilities can affect public health and safety, reduce productivity, and cause long-term financial losses when buildings must be prematurely renewed or replaced. An appropriate budget allocation for routine maintenance and repair of buildings will typically range from 2 percent to 4 percent of the aggregate current replacement value of those facilities (excluding land and major associated infrastructure) (NRC, 1990).

Funding requirements to support new buildings include the appropriation of an adequate maintenance and repair budget and adequate staff to operate and maintain the building. The former is necessitated both by the simple increase in building stock of the institution and by the greater complexity, with its greater probability of malfunctioning, of the new facility. The latter is necessitated both by the increase in building stock and by the greater technical knowledge needed to ensure the optimum performance of a more complex structure.

Condition Assessments

Supporting a facility throughout its lifetime requires ongoing knowledge of the condition of the building. Condition assessments should therefore be done regularly to provide building information for appropriate maintenance and identification of necessary repairs.

The daily walk-through by the building engineer is an informal condition assessment, providing information on the immediate needs of the building. The building engineer also uses this information, coupled with the operations and maintenance manuals, to plan operating and maintenance activities for a week or month at a time.

Condition assessments are also performed on a more formal basis by the client's facilities staff or by professionals contracted for this activity. These more formal assessments are performed to determine building deficiencies and to develop project scope of work and cost estimates. This is done to decide on the work and budget required for both short-term projects and long-term facility plans.

RECOMMENDATIONS

To address process issues during the several phases of a laboratory construction or renovation project, the committee recommends the following actions:

1. **Develop a planning and decision-making process.** Planning should include all relevant participants. Decisions should not be revisited without cause.
2. **Implement a predesign phase.** Predesign, involving a design professional, maximizes end results.
3. **Designate a single point of contact for each group.** This individual will coordinate all information exchange within the group and with the other (client, design, and contractor) groups.
4. **Maintain control of the budget.** Detailed cost estimates should be completed and reviewed at the conclusion of each phase. A clear process for handling change orders should be developed before construction begins.
5. **Establish a system for rigorous review and approval of documents.** Design documents should be carefully reviewed and approved by the client group representative at the end of each phase.
6. **Establish and implement a process for building commissioning.** Building commissioning should include the production of operation and maintenance (O&M) manuals, updated construction documents ("as-builts") and drawings, systems testing, and training. There should also be a postoccupancy evaluation.
7. **Owners should be good stewards.** Beginning at the planning stage and continuing for the life of the laboratory facility, owners must provide adequate funding and staffing for operation and maintenance of the buildings.

3

Technical Issues

All building renovation or construction, and especially laboratory renovation or construction, involves many issues that must be resolved and many decisions that must be made. Although it is possible to delegate these tasks to the design professional, the active participation of an informed client in the resolution of these issues and in related decision making greatly enhances the probability that a superior result will be obtained.

Some of the details and issues, such as those dictated by environmental health and safety (EH&S) regulations, are highly specialized and should be left to the experts. Others, such as design alternatives or considerations affecting construction costs, need to be reviewed, discussed, and resolved jointly by members of the client group—such as the client team and user representative—and the design professional. The client team and the user representative should therefore be familiar with these issues so that they are able to make informed decisions. Although an experienced design professional can usually be relied on to inform the client of all possible design alternatives, there are, unfortunately, exceptions. Not only can an informed client interact more satisfactorily with the design professional, but knowledge of design considerations also better enables the client to evaluate the design professional's competence. If in-house architectural staff are experienced in laboratory design and construction, they can help carry out some of these roles.

ENVIRONMENTAL HEALTH AND SAFETY

Throughout the planning, design, and construction phases of a laboratory renovation or construction project, careful attention to EH&S issues is essential to ensure that the facility can be built and occupied. EH&S issues influence every major decision—from site selection to suitability of the building for occupancy. Further, careful attention to these issues is important in interactions with the neighboring community, which may be passionately concerned about the local impact of a chemical facility. Community relations issues are discussed in Chapter 1.

Careful consideration of EH&S issues will enable the project team to comply effectively with the complex and sometimes conflicting array of federal, state, and local regulations, codes, and ordinances that affect construction and operation of laboratories. It is important to recognize that codes and regulations governing the construction, renovation, and operation of laboratories and the undertaking of a building project by an institution have a common objective—to guarantee that the building and the environment surrounding it will be safe. This common ground can make it possible to reach practical solutions to problems that may arise in the highly intricate regulatory setting that governs laboratory design and construction. When there is conflict, the good judgment of knowledgeable individuals should prevail.

This section summarizes the legal bases for, and prudent responses to, the multiple regulations, codes, and ordinances that affect the construction and operation of laboratories. The committee emphasizes that every major building project team should have the support of EH&S professionals throughout all phases of the laboratory facility design and construction process. Expertise provided by these professionals will help the client team set health and safety objectives for the project, select appropriate engineering criteria to meet those objectives, and identify soundly conceived strategies for achieving compliance with regulatory requirements. EH&S professionals should also be involved in the commissioning process that precedes occupancy of a newly constructed or renovated facility to help ensure the operational integrity of all engineering systems that protect the occupational health and safety of the laboratory users. A knowledgeable member of the institution's EH&S program should serve as a technical advisor to the client team. This person should be well informed about the program of requirements for the facility; have expertise in laboratory safety, environmental protection, and pollution control; be experienced in working with the cognizant regulatory authorities; and be familiar with facility engineering systems that can create effective, safe, and compliant laboratories.

Codes and Regulations

Construction or renovation of a laboratory building is regulated mainly by state and local laws that incorporate, by reference, generally accepted standard practices set out in uniform codes. Box 3.1 lists the kinds of codes that affect most laboratory construction projects. The codes are usually administered at a municipal or county level but some locations may be administered at a regional

BOX 3.1 Types of Code Requirements That Affect Most Laboratory Construction Projects

- Ventilation—to maintain comfort and occupational health
- Fire prevention—to detect and suppress fires, in part by limiting quantities of flammable and hazardous chemicals
- Emergency power supply—to maintain operation of vital life-safety systems such as egress lighting, fire detection, and protection systems during electrical interruption
- Control of hazardous gases—to reduce the risk from and to control accidental releases of gases
- Building height—to limit the height of laboratory buildings based on chemical usage
- Seismic requirements—to reduce the hazards posed by earthquakes

or state level. Scheduling the obtaining of permits required for construction will help prevent unnecessary delays in a project.

It is important to give permit-granting agencies early notification of significant construction projects within their jurisdiction so that they can anticipate their workload and staffing needs. Agency professionals can offer guidelines and insight into unique local needs that could influence a building project. Agencies in some jurisdictions like to set up a single point of contact between the agency and representatives of the project team, usually the client and architect project managers, to facilitate and coordinate the exchange of important information and to establish a good working relationship. One benefit of this structure is that it minimizes the number of people who have to spend time learning the unique processes and procedures of the organizations involved, thus optimizing communication. When an agency has clear and sufficient information about a complicated research facility construction project before actual plans are submitted, it can move more quickly through the required approval and permit-granting process.

Generally, a project must comply with building, fire, electrical, plumbing, and mechanical codes at the local level that may be prescriptive or performance based. Because agencies have widely varying levels of experience in evaluating complex facilities like research buildings, outside experts can be a valuable investment toward timely inspection of plans and construction site activities. Some codes allow hiring mutually acceptable outside experts for plan review and construction inspection, should the agency need the added expertise or personnel to expedite a project.

Local codes often include nationally recognized standards developed by organizations such as the National Fire Protection Association (NFPA), the American National Standards Institute (ANSI), the American Society for Testing and Materials (ASTM), and the American Society of Heating, Refrigeration, and

Air-conditioning Engineers (ASHRAE). These organizations often adopt standards by consensus of a committee of nationally recognized experts. Many institutions and professional associations have members on a standards committee, who could be a valuable resource to a laboratory construction project team.

Both codes and the national standards evolve over time. Additions and revisions are based on advances in science and technology and on knowledge gained from accidents or incidents involving significant loss of life or property, or environmental damage. A summary of codes existing as of 1995 is contained in Mayer (1995).

As this current report was being written, the three regional code organizations—the International Conference of Building Officials (ICBO), the Building Officials and Code Administrators International (BOCA), and the Southern Building Code Congress International (SBCC)—were drafting one uniform national code. Adoption of this building code is projected for the year 2000. Even when there is a uniform national code, however, some large cities may still have their own codes or amendments to the national code to deal with local concerns and circumstances.

Environmental Issues

Four major acts of Congress that set the national agenda on environmental protection have a direct bearing on the operation of laboratories. The Resource Conservation and Recovery Act (RCRA) addresses waste disposal and reduction. The Clean Air Act (CAA) concerns air quality and its effects on human health. The Federal Water Pollution Control Act covers the improvement and protection of water quality. Title III of the Superfund Amendments and Reauthorization Act (SARA) ensures a community's right to know what hazardous materials are present in facilities in their community, which enables community emergency response authorities and local fire departments to protect themselves when responding to a fire, explosion, gas or chemical release, or other emergency. Communities are rightfully concerned about what is occurring in their neighborhoods. A laboratory construction project team must become familiar with the requirements associated with relevant environmental regulations to ensure that the completed project achieves compliance.

A major objective of much of this legislation is pollution prevention. SARA Title III is intended to enhance communication between facilities that use hazardous chemicals, the communities in which the facilities are located, and the emergency response organizations of those communities. Laboratory facilities should develop excellent programs in pollution prevention, emergency response planning, communication, and public outreach. This means going beyond regulatory compliance to ensure constructive responsiveness to community concerns. Doing so will foster good relations with the community and will ease conflict that too often arises in the construction of new laboratory facilities. Means to encourage support are discussed in the "Community Relations" section in Chapter 1.

Managing Hazardous Waste

Under RCRA, the Environmental Protection Agency (EPA) is responsible for promulgating and enforcing prescriptive regulations for controlling hazardous waste at all stages, from generation to disposal. The regulatory philosophy of the EPA is to treat laboratory and industrial-scale waste generators in the same way, although there are significant differences between the two in terms of waste volume produced and number of chemicals handled, as well as in the associated potential environmental risks. Universities, in particular, have had great difficulty in implementing an industrial-scale regulatory model to manage hazardous chemical waste generated in individual laboratories.

Management of hazardous waste must be considered by the project team in planning and designing a laboratory facility. The team must understand the life cycle of chemicals within the facility; how they are purchased, delivered, centrally stored, moved to individual laboratories, used, converted to waste, further treated, and packaged for disposal. The establishment of a system to handle this process is important for the safe operation of the facility and to ensure regulatory compliance and cost containment.[1]

Controlling Chemical Vapor Emissions

The 1990 amendments to the CAA require the EPA to vigorously regulate emissions of sulfur dioxide, volatile organic compounds, hazardous air pollutants (HAPs), and ozone-depleting chemicals. Large institutions with laboratories are affected by these rules if they have the potential to emit one or more of the EPA-listed HAPs in amounts greater than 10 tons per year for a single HAP or 25 tons per year for total HAPs. These quantities include emissions from all sources in a contiguous area and under control of a common authority, such as an institution's power plant and boilers and its laboratory facilities. For these reasons, the chemical vapor emissions from individual fume hoods at larger institutions may be required to meet emission standards that the EPA designates based on "maximum achievable control technologies," a sliding scale that changes as technology changes.

The 1990 amendments also require the EPA to establish a separate category covering research or laboratory facilities as necessary to ensure the equitable treatment of such facilities. The result may be a regulatory model for laborato-

[1]Users can assist by attempting to identify opportunities to reduce waste generation through substitution of less hazardous chemicals or adopting procedures that require smaller quantities of chemicals; recycling, reusing, or recovering chemicals before they become a part of the waste stream; and implementing bench or facility waste treatment. Additional suggestions for working with chemicals are given in Chapters 4, 5, and 7 of *Prudent Practices in the Laboratory* (NRC, 1995). The publication, *Less Is Better: Laboratory Chemical Management for Waste Reduction* (ACS, 1993), addresses micro-scale experimentation that promotes waste minimization.

ries that recognizes the differences between laboratories and major industries, although it is unlikely to provide relief for major institutions with laboratories that already exceed the limits on quantity of controlled materials emitted.

The potential need for treatment of air exhausted from fume hoods is a major environmental issue affecting laboratory design and presents a daunting challenge for the laboratory designer. Technology for maximum achievable control will increase cost and space requirements. Uncertainty about the requirements of a revised EPA regulatory model for laboratories may justify providing additional space to accommodate future emission control technology, should it be required, to reduce retrofit costs. Current hood use practices should be reviewed by the user representative to explore ways in which air emissions could be reduced. For example, experiments and other operations conducted in hoods should be planned so that they never involve the intentional discharge of hazardous emissions, and control apparatus such as condensers, traps, or scrubbers (to contain and collect waste solvents, toxic vapors, or dusts) should be incorporated into the experimental process. Thus, hazardous materials should be vented from the fume hood only when, in an emergency, a chemical is accidentally released within the hood. Such planning will simplify the problem of treating fume hood exhausts.

Controlling Liquid Effluents

Liquid effluent discharge from laboratories is less difficult to handle properly than is vapor exhaust. Requirements controlling the discharge of pollutants are set by the local sewer authority or publicly owned treatment works (POTW). Sinks are no longer used to dispose of hazardous laboratory waste. Waste water from laboratory sinks must flow through an acid neutralization system that adjusts the pH of the effluents prior to their discharge into the POTW. In new construction this requirement is generally met by installing a central building dilution tank with a monitoring system that measures pH and automatically adds acid or base to ensure compliance with effluent standards. Early communication with the POTW about the intentions of the institution to install such systems in a new laboratory facility will help maintain the good record of compliance that laboratories have in this area of environmental protection.

Health Issues

Under the Laboratory Standard promulgated in 1990 by the Occupational Safety and Health Administration (OSHA), an institution or employer with laboratories is required to develop its own program to protect the health and safety of its employees. This standard represents a welcome and significant departure from the conventional approaches of regulatory agencies that issue detailed prescriptive standards. An institution-developed program, called the Chemical Hygiene Plan, must meet performance standards set by OSHA. Information in the plan will help guide the development of a healthful and safe laboratory environment. The project team should be familiar with its institution's Chemical Hygiene Plan—the centerpiece of the regulatory program—and refer to it throughout the design process.

Laboratory Chemical Hoods

The fume hood is the principal device used in a laboratory facility to protect the health of workers. The selection, placement, and installation of the fume hood collectively constitute the most important health-related issue the project team will consider. Decisions affecting the entire building's ventilation system, which is perhaps the major cost component of any new laboratory construction or renovation project, will be influenced by hood-related choices. Poor selection and installation of fume hoods will create a serious problem that either endangers the health of workers or drastically curtails the use of the laboratory for potentially hazardous experiments. The design group must accept responsibility for ensuring that the facility fume hoods and ventilation system are properly designed to provide a healthful and safe laboratory environment.

The selection of the proper fume hood requires specific information about the intended use of the hood and the institutional policies that may limit the choice of hood. Kinds of user information that should be obtained in the predesign phase are shown in Box 3.2. Some relevant aspects of institutional policies affecting hood use and design are in Box 3.3.

The number and size of necessary hoods will vary considerably with the type of laboratory. For example, biochemistry laboratory experiments involve minute quantities of chemicals and are usually performed on the open bench. A single hood that provides 6 linear feet of working space may be sufficient to support the needs of several bench scientists who occupy 600 square feet of biochemistry laboratory space. For general chemistry laboratories, one hood providing 5 to 6 linear feet of working space at the face would be the minimum requirement for every two workers. There will be an even higher requirement for hoods in organic and inorganic synthesis laboratories, where a single chemist

BOX 3.2 Information Needed for Hood Selection

- Equipment and activities that require containment within a hood
- Properties of materials that will be used in a hood
- Quantity of materials that will be used in a hood
- Number of people who will use a hood and the frequency and duration of use
- Anticipated changes in future use

BOX 3.3 Elements of Institutional Policies Related to Hoods

- Requirements for performance and containment
- Density of hood use
- Requirements for limitations affecting the ventilation system
- Cost
- Requirement for fume hood controls—occupancy sensors

may require 8 linear feet of working space to contain equipment and other experimental apparatus. The density of hood use in synthetic laboratories could approach a single hood that provides 6 to 8 linear feet of working space at the face of the hood for every 100 square feet of laboratory space. Benchmarking hood use in comparable institutions can be a valuable guide in selecting the type and the number of hoods.

Laboratory Ventilation System

The density of hood use will have a significant impact on the design of the ventilation system because of the large quantity of air that will be exhausted to the outdoors by properly functioning hoods. The ventilation system in chemical laboratories must satisfy two principal health-related objectives: occupational health, which is achieved through the proper installation and operation of chemical laboratory hoods, and occupant comfort, which is achieved by heating and humidifying the general laboratory air in the winter and cooling it in the summer.

A secondary function of the laboratory ventilation system is to prevent the migration of contaminants caused by incidental and accidental release of chemicals from the laboratory into other areas of the building. This is accomplished in part by providing single-pass air (air discharge from the laboratory directly outdoors) and in part by controlling the direction of airflow. The ventilation system should be designed so that air will flow from the areas with the least potential for contamination toward areas with the highest potential. Caution in setting system design parameters is important to ensure that safety considerations do not significantly increase cost. For example, a design requirement that the system should maintain designated pressure differentials rather than simply satisfy the objective of unidirectional airflow may substantially increase the cost of the project.

An enormous amount of energy can be consumed in conditioning the quantity of air that is delivered to laboratories to maintain comfort and ensure safe operation of the chemical hoods. Since laboratory air is not recirculated but instead is discharged as single-pass air, much energy is wasted. This problem is significantly exacerbated as the magnitude of hood use increases.

Fiscal responsibility provides a strong incentive to implement energy conservation in the design of laboratory ventilation systems so that utility cost savings can be achieved. Energy-efficient systems will most certainly be required for laboratory buildings with high hood use. Technical details of different hood designs are outlined in the "Laboratory Configuration" subsection of the "Design Considerations" section in this chapter and are discussed in Chapter 8 of *Prudent Practices in the Laboratory* (NRC, 1995).

The principal approach to conserving energy and reducing operational costs is to reduce the quantity of conditioned air that flows to the outdoors through laboratory chemical hoods. The project team should recognize the inherent conflict between the objectives of conserving energy and preserving the health of laboratory users. Reducing the airflow to hoods can increase the hood users' risk. Nevertheless, it makes sense to reduce airflow during times when the number of hoods in use is significantly reduced. Changing airflow characteristics in an operating ventilation system without compromising occupational health is an achievable, but daunting, engineering and operational challenge. Selecting a competent and experienced mechanical engineer to design an energy-efficient ventilation system will help ensure that operational reliability is achieved and that energy conservation and occupational health are compatible as objectives. Such design solutions are complex, and their initial costs will be high. Operating costs, conversely, will be lower than the cost of using conventional hoods. The institution must also recognize that continued operational reliability will be an essential requirement for maintaining a healthful environment. The completed system will require a sophisticated staff of facility engineers and a dedicated preventive maintenance program. While planning for a healthful, energy-efficient ventilation system, the project team must ensure that cost considerations never take precedence over the institution's moral and legal obligation to protect the health of the worker and the environment. If there is a question, EH&S professionals should be consulted.

Unique and Particularly Hazardous Operations

It is important for the project team to identify operations or processes that involve highly hazardous chemicals or that may present unique hazards. A useful first step would be to review the types of operations, protocols, and experiments that are not allowed to be performed without the prior approval of the institution. The Chemical Hygiene Plan is a good resource for this information as it describes the circumstances under which administrative controls would be put into place. Both scientists who carry out these operations and EH&S professionals should be consulted in developing any design strategy to control risks associated with these types of operations. It is important to ensure that the controls are relevant to the risks, are practical to implement, and comply with regulatory requirements. User input in these decisions will afford higher levels of operational compliance in the completed facility.

Processes presenting unique hazards will require careful consideration by experienced users and consultants. Chemistry is becoming the universal language of science, and the planners of new chemistry buildings should anticipate that space requirements in some situations may differ considerably from those associated with traditional chemistry laboratories. For example, mutual scientific interests among combinatorial chemists, synthetic chemists, and molecular biologists have encouraged the placement of modern biology laboratories in close proximity to organic and inorganic synthesis laboratories to facilitate collaboration.

Future chemistry laboratory buildings may likely have requirements for laboratory space appropriate for experiments involving human pathogens. If a requirement such as this arises, the project team will need to become familiar with consensus standards for the design and operation of safe biological laboratories. An authoritative reference on biological safety is Richmond and McKinney (1993). Guidance for facility safeguards is provided according to four levels of risk that are based on the potential for occupationally acquired infection and the severity of disease.

Areas that can present unique hazards—such as high-pressure facilities; radiochemistry, x-ray diffraction, nuclear magnetic resonance (NMR), and high-energy laser laboratories; and laboratories for research in which the risk of explosion is high—are likely to be included in the program of requirements for new facilities or major renovation projects. Other potentially hazardous areas include those that contain large volumes of chemicals, such as chemical storage or hazardous waste accumulation areas. Each of these areas will present special hazards for which expert consultation will be required to ensure that appropriate criteria are identified to achieve a safe design.

Access Control

The concept of controlled access is relevant in all areas that may be hazardous to health. The objective is to protect persons who are not assigned to the laboratory from exposure that may compromise health. The degree of control over access should correspond to the level of risk. For example, in high-risk areas, access should be limited to individuals specifically trained and assigned to work in the area. In low-risk areas, it may be sufficient to design laboratory corridors so that they are not perceived as public thoroughfares.

The configuration of space so as to control access merits careful consideration, particularly for laboratory areas that require limited access. It is important that both the controlled areas and the access points to these areas be easily recognized as such. There should be a way to inform the visitor of appropriate entry procedures or prohibitions against entry. The location of a controlled access area should be convenient for the laboratory staff. It is equally important that access control measures be no more restrictive than the potential risks require; otherwise, they will be quickly abandoned by the assigned laboratory staff.

Safety Issues

The Occupational Safety and Health Act of 1970[2] established two principal duties for each employer covered by the act. The first duty requires that each employer "shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees." The second duty requires that each employer "shall comply with Occupational Safety and Health Standards promulgated under this Act." These duties underscore the need of an employer to insist that a new or renovated facility promote, rather than hinder, safe occupancy. The initial Occupational Safety and Health Standards promulgated under the act addressed workplace safety hazards that were known to cause physical injury to workers. OSHA continues to emphasize an employer's responsibility to safeguard workers from electrical, mechanical, and fire hazards, as well as from exposure to flammable, corrosive, reactive, and toxic chemicals. All of these physical hazards have relevance to the design, construction, and operation of chemical laboratories.

Several safety issues that need to be addressed by the project team are briefly described below. They are intended to highlight the importance of addressing physical hazards that could cause injury to workers as a result of the poor design of chemical laboratories.

Emergency Egress

The most important safeguard for preventing serious personal injury that a building can provide is a means of egress that will permit the prompt escape of building occupants in case of fire or other emergency. The means of egress consist of three separate and distinct parts: the pathway of exit access, the exit, and the pathway of exit discharge. Local fire codes and OSHA standards require that a means of egress be a continuous and unobstructed route from any point in the building to a public way.

In chemical laboratory buildings, the exit access comprises the hallways and corridors that lead directly from a laboratory module or work area to the entrance of a designated exit. This part of the means of egress must provide an unobstructed path of travel both to promote the fast and orderly exit of building occupants and to allow emergency responders to gain safe and efficient access to the emergency scene. These functions can best be preserved if the corridors are designed so that they do not encourage misuse. For example, if a laboratory corridor that serves as an exit access is designed with a greater width than is

[2]P.L. 91-596, Occupational Safety and Health Act of 1970 section 5, codified at 29 USC 651 et seq.

necessary to provide for efficient travel of staff and movement of supplies and equipment, it is inevitable that a portion of the corridor will be used for storage of equipment and supplies. In the absence of rigorous administrative controls, obstructions will occur and safety will be quickly compromised. Another occasional design deficiency that invites corridor misuse is the placement of columns that project into corridor spaces. Extending the laboratory wall to the corridor side of the column solves the problem and provides more space for laboratory use.

Emergency Equipment

Safety showers and eyewash fountains are essential emergency equipment in chemical laboratory buildings. Design requirements are specified in national consensus standards, such as ANSI Z358.1-1990, that by rule have been promulgated as OSHA Occupational Safety and Health Standards. Safety showers and eyewash fountains should be available in areas where chemicals are handled. Safety showers should be located in the corridor near the exit doors from each laboratory module or in the laboratory on the hinged side of the exit door. It is preferable that all safety showers be placed in a standard location throughout the laboratory building to facilitate occupants' awareness of their location. The safety showers should be equipped with a rigid pull-down delta bar. Chain pulls are not advisable because they can hit the user and be difficult to grasp in an emergency. While vanity curtains should be discouraged as they interfere with efforts to provide emergency treatment, the inherent conflict between modesty and safety needs to be addressed.

Eyewash fountains should be placed in a dedicated and standard location. Travel time from any potential source of exposure to the eyewash fountain should be less than 10 seconds. While the laboratory sink appears to be an obvious choice for placement of an eyewash fountain, normal sink functions often obscure the presence of the fountain or obstruct access. A dedicated place close to or part of the emergency shower is therefore more desirable. The location of eyewashes and safety showers needs to be coordinated with laboratory security provisions. An eyewash fountain should provide a soft stream or spray of aerated potable water for at least 15 minutes. Fountains that flush both eyes simultaneously should be installed.

Dedicated Storage Space

The safety of occupants in a chemical laboratory building and compliance with environmental regulations can be improved by providing dedicated and appropriately designed space for storage of chemicals, hazardous waste, and emergency equipment. The requirements for storage of chemicals in stockrooms and laboratories will vary widely depending on local code; the quantity, hazardous nature, and characteristics of the chemicals; and the nature of the laboratory operations. A careful review of all requirements by the project team is needed to ensure an adequate design for chemical storage space and to safeguard this space against reappropriation to other functions. Special attention should be given to storage requirements for flammable and combustible liquids, gas cylinders, highly reactive substances, toxic materials, and controlled substances.

Dedicated space within or near the laboratory is desirable for the accumulation and temporary storage of hazardous chemical waste materials. These areas could also be used to foster and support recycling and reuse programs. Safety considerations should be a primary concern in the design of these spaces. For example, the areas should not interfere with normal laboratory operations, and ventilated storage may be necessary. In larger accumulation areas, it may be necessary to consider fire suppression systems, ventilation, and dikes to avoid sewer contamination in case of spills. Requirements for such space should be specified by the EH&S program staff.

A central storage area for emergency equipment will improve the effectiveness of emergency-response functions. Space should be provided for storing self-contained breathing apparatus, blankets for covering injured persons, first-aid equipment, personal protective equipment, and chemical spill cleanup kits and spill-control equipment. The need and requirements for this space should be coordinated with the EH&S official responsible for managing the facility's emergency-response program.

Workers with Disabilities

The well-designed chemical laboratory should provide, or be capable of being easily modified to provide, reasonable accommodations for qualified workers with disabilities. Reasonable accommodation may include making laboratories readily accessible to and usable by individuals with disabilities and by acquiring or appropriately modifying equipment for use by individuals with disabilities. Most laboratory designs that allow simple rearrangement of casework—i.e., laboratory cabinetry—can be easily adapted to provide reasonable accommodations for workers with disabilities. Many accommodations will also improve the safety of occupants without disabilities. For example, keeping aisle space clear of obstructions to accommodate workers with impaired mobility will enhance everyone's safety. Special hardware that makes it easy to open and close doors can benefit all laboratory workers who carry supplies and materials from one laboratory to another. In considering reasonable accommodations for workers with disabilities it is necessary to ensure that the accommodation will not result in a significant risk to the health or safety of other workers. Qualification statements for workers with disabilities who seek employment in chemical laboratories should include a requirement that an individual shall not pose a direct threat to the health or safety of other individuals in the laboratory.

Space Layout Issues

Laboratory worker safety is an important consideration when determining the specific layout for laboratory equipment, casework, and work desks. Worker safety issues, for example, should take precedence over program needs in determining the appropriateness of open laboratories for chemical operations, the location of chemical laboratory fume hoods, the location of entrances and exits, and whether student work desks should be included within the operational area of a working laboratory. Other aspects of these issues are discussed in the section on "Sociology" in Chapter 1.

Open laboratories have had a positive effect on improving laboratory occupants' compliance with safety requirements. Peer pressure can be persuasive in elevating the standards of individuals whose commitment to safety falls below the standards set by the group. But open laboratories are not appropriate for laboratory operations that present moderate to high risks or for laboratories where the level of safety practice appropriate for the work conducted by individuals in the laboratory varies considerably. Generally it is not advisable to adopt an open laboratory design concept if the potential risks associated with laboratory operations require formal access control measures.

The placement of laboratory fume hoods should allow alternate routes of egress so that laboratory personnel do not pass in front of the face of the hoods in emergency situations. A desk or seated workstation should never be located directly across the laboratory aisle from a hood. Hoods should be placed in low-traffic areas away from doors and air supply grills to prevent air turbulence that could compromise hood performance.

Generally student desks should not be located in working laboratories that present moderate to high occupational risks. Desks may be provided for students in low-risk laboratories, but the placement of the desks should be carefully considered by the laboratory supervisors and the project team's EH&S professional. For example, student desks should be placed near an exit door so that students will not have to move through a hazardous area to reach the exit, but the desks should also be located such that they do not create a barrier to emergency egress.

DESIGN CONSIDERATIONS

Laboratory users involved in the predesign or design phase of a research laboratory project often have preconceived impressions of what features their future laboratory must have. However, laboratory users often lack experience in laboratory design and so may be unfamiliar with design issues, possible design alternatives, or methods of evaluating those alternatives. The design considerations described in this section are unique to laboratory buildings. While some of the design approaches discussed in this chapter may increase construction and

BOX 3.4 Examples of Large- to Small-Scale Design Considerations

1. Building and site issues
   - Renovation versus new construction
   - Building site
2. Floor planning
   - Adjacencies
   - Traffic flow
3. Laboratory configuration
   - Individual laboratories
   - Support spaces
4. Building services and structure

operation costs, they are critical to the functionality of the facility and the safety of the building users and surrounding community. Users' familiarity with alternative approaches to specific laboratory design issues will most likely lead to a more efficient, cost-effective, flexible, safe, and environmentally appropriate laboratory facility. Although an experienced and knowledgeable design professional can assist in the identification of design issues to consider and can evaluate appropriate alternative approaches to laboratory design, this is not always the case. Even when an experienced and knowledgeable design professional is available, it is advantageous for the user representative and the client team to become informed consumers of the design professional's services.

The design considerations presented here range from those requiring large-scale decisions, such as constructing a new building versus renovating an existing building, through intermediate-scale options, such as floor planning, to small-scale issues, such as laboratory configuration. They also include considerations related to structural as well as mechanical, electrical, and plumbing (MEP) systems (Box 3.4). Administrative policies should be considered throughout, since many institutions have defined practices or standards that affect many design issues. Many of the design considerations are interdependent. Decisions regarding larger-scale issues, which should be made early in the design process, can limit or preclude many of the smaller-scale design decisions. Knowledge of these dependencies, often provided by the laboratory design professional to the client team, will help streamline the design process and maximize the potential for a cost-effective and optimum design solution.

Some of the design considerations discussed in this chapter include specific alternative approaches. What is acceptable as an alternative in laboratory design may differ according to scientific discipline. This report focuses primarily on chemical, biochemical, and molecular biology laboratories, but it is also relevant to laboratories in related disciplines such as food science, agricultural science, pharmacy, materials science, some engineering sciences, and physics. However, the requirements of highly specialized laboratories, such as animal facilities, are covered in other guides such as the *Guide for the Care and Use of Laboratory Animals* (NRC, 1996). Richmond and McKinney (1993) provides design details for laboratories using identifiable infectious agents.

Acceptable design alternatives also differ between organizations on the basis of their goals, geographic location, governing authorities, and other factors. The goals for a new research laboratory building or renovation should be determined in the early stages of planning as they will influence the development of appropriate design alternatives. Geographic location may influence the acceptability of a particular design alternative; for example, the more stringent seismic requirements of building codes in southern California, as compared to New Jersey, will influence the overall height of the laboratory building in California both because of the increased structural costs associated with the applicable building codes and because of building height restrictions. Similarly, the authority of local governing authorities to interpret zoning regulations, building and fire codes, and other local regulations can influence the design of the laboratory facility.

Choosing between the different alternatives is a complex process that must strike a balance between benefits and costs. The latter include construction, total project, operation, and lifetime costs of the building; these costs are discussed in the section on "Research Laboratory Cost Considerations" in this chapter. When choosing between the different alternatives, other factors besides costs and benefits also need to be considered (see Box 3.5).

Of all the criteria noted in Box 3.5, flexibility is the one that often pervades all the design considerations discussed in this chapter. Flexibility, which is also referred to as adaptability, is the ability of a building site, building design, or individual laboratory to meet both current and unforeseen future needs. Future laboratory additions, renovations, and modifications can be implemented cost effectively, in a timely manner, and with less disruption to other users if the laboratory facility is designed to be flexible. Flexibility may come at a modest increase in the initial construction cost; however, because numerous changes will be made to a laboratory over its lifetime, the cost incurred to design and

BOX 3.5 Criteria for Evaluating Design Alternatives

- Present versus future costs
- Tangible and intangible benefits
- Zoning environmental requirements
- Schedule and time to completion
- Operating versus capital costs
- Functionality
- Aesthetics
- Flexibility

BOX 3.6 Building Design and Site Selection Issues

- New construction/ addition/ renovation
- Building site
- Zoning and regulations
- Building height and footprint
- Building air intake and exhaust
- Campus interactions
- Access to the building
- Total environmental design approach

build a flexible laboratory building will be more than recovered over the lifetime of the laboratory.

Building Design and Site Selection

Designing and siting any large building involves many considerations, some of which are given in Box 3.6. Siting a laboratory facility requires attention to all those listed and others. Some issues, such as new construction versus renovation, must be resolved before others can be considered. Others, such as building height and number of floors, are interrelated. The resolution of some, such as desired interactions, depends on the sociology of the institution. Others, such as zoning, require the participation of specialty consultants. A master plan and a facilities program should be successfully completed before any decisions are made about building design and site selection.

The resolution of these issues requires a large number of participants. The design professional should assist the client team to understand the dependencies of some of these issues, and expert consultants should be engaged where necessary. The process discussed in Chapter 2 should be used.

Renovation Versus New Construction

The predesign phase of the laboratory project often includes a recommendation to renovate an existing facility, build an addition to an existing facility, build a new facility, or combine the three approaches. The recommended renovations may involve an existing laboratory building, or the conversion of a non-laboratory building to laboratory use. The primary advantage of renovating an existing building is the potential savings that result from reuse of the existing structure, enclosure, partitions, and MEP systems and equipment. However, for large renovations or additions, the potential savings may be minimal because some or all of the building components may require modification or rehabilitation. For example, the building structure may require reinforcement either to accommodate programmatic requirements related to loading or vibration-free environments or to comply with current building codes. Programmatic requirements may also necessitate modifications to the building enclosure or demolition and reconstruction of existing partitions, or both. Changes may also be needed to facilitate repairs. The existing MEP systems and equipment will most likely require replacement or substantial modification to extend their useful life or to meet programmatic requirements. On the other hand, it may be necessary to renovate if the existing building is designated as historical.

One advantage of building an addition is the potential for reducing costs by simply extending the existing MEP systems. Such savings are most often realized if the existing MEP systems and equipment were initially designed with future additions in mind. If the MEP systems were not designed and sized to be extended, the necessary modifications to the existing system will reduce the potential savings. Another advantage to building an addition versus a new free-standing building is its proximity to existing facilities; connecting adjacent facilities could support the trend towards collaboration, interaction, and interdisciplinary research.

Building Site

If the predesign recommendation is to construct an addition or a new building, a building site must be selected. While the selection process for a building site is complicated by many factors and can be difficult, the decision regarding the building site should ultimately be based on a total environmental approach. How does the building fit into the campus and community? What demands are placed on the natural and man-made environment? (See Box 3.7.) Construction of a laboratory building, as with any large building, places demands on the local infrastructure of roads and utilities. Improvements to the infrastructure are often required, and the cost has to be borne by the project, the sponsoring institution, or the local community. For example, electric power, telephone and communications lines, and sewer and water connections may have to be upgraded. For corporate and academic campuses with other centralized utilities, such as steam

BOX 3.7 Demands Made on the Environment by Laboratory Facilities

Natural Environment
- Air quality
  —Building emissions
  —Traffic emissions
- Water quality
  —Building effluents
  —Storm water runoff

Man-made Environment
- Transport of hazardous materials
- Additional vehicular traffic
- Space for parking
- Fire protection
- Access for emergency response

BOX 3.8 Elements of the Regulatory and Legal Environment Affecting Laboratory Renovation and Construction

- Laws
  —Clean Air Act
  —Clean Water Act
  —Americans with Disabilities Act
- Zoning requirements
- Fire codes
- Access and parking requirements
- Pedestrian access
- Historic designation
- Required permits
  —Occupancy
  —Sewage
  —Building
  —Use

for heating and cooling water, expansion of or upgrades to the central power plant and cooling towers may also be needed.

Zoning Laws, Codes, and Regulations Affecting Building Design and Site Selection

The zoning, permit, and regulatory process can influence the design, use, construction start-up, progress, and occupancy of the research laboratory facility. A laboratory building must comply not only with the laws, codes, and regulations to which any building must conform but also with additional legal and regulatory restrictions specific to laboratories and the work conducted within them. Many of the kinds of restrictions and considerations affecting the use and design of laboratory buildings are listed in Box 3.8, and some of these are discussed in the "Environmental Health and Safety" section above in this chapter. Requiring permits is a routine aspect of the regulatory process. Building, occupancy, use, air rights, storm water, and sewage permits may all be required in a laboratory construction or renovation project.

Zoning regulations often dictate the acceptable use of the proposed building site and can place severe restrictions on the siting and design of a laboratory building. They may restrict or regulate the building height, footprint size, users' parking, service requirements, building appearance, landscaping, and even the intended use of the building. Zoning regulations and building codes governing the use, storage, and disposal of potentially hazardous materials, which are common in laboratory facilities, can influence the location of a new laboratory building or an addition to a laboratory building. Zoning regulations and building and fire codes can restrict the conversion of an existing nonlaboratory building and the renovation of an existing laboratory building.

The zoning and building permit processes in many communities may require public hearings and interagency reviews. A municipality's call for public comment can politicize proposed construction if appropriate community support is not sought. Methods for engaging community involvement are discussed in the "Community Relations" section of Chapter 1.

Building Height and Footprint

The maximum allowable building height in a given locality is commonly limited by zoning regulations and local building and fire codes based on the nature of the activities conducted in the building and the potential fire hazard created by the use of flammable materials. The height of each floor is influenced by programmatic requirements related to MEP systems and the desired ceiling heights in laboratories. A floor-to-floor height of 15 to 16 feet is common, although in some types of laboratories 12 feet suffices, and in buildings with interstitial floors a greater floor-to-floor height is necessary. Interstitial floors are service floors between the laboratory floors that provide dedicated space for MEP equipment and air and water distribution systems to the laboratories.

The combination of the maximum allowable building height and the floor-to-floor height will limit the number of floors that may be built on a site. If a specific gross square foot area is wanted, a building with fewer floors will require a larger footprint to obtain that amount of gross square foot area. Zoning regulations, however, can also restrict the maximum allowable footprint. Restrictions imposed by zoning regulations concerning the building footprint and height can exclude certain sites from further consideration based on the amount of gross square feet needed in the proposed building.

Regardless of the restrictions on height and footprint size, the overall size of the proposed building or addition should strike a balance between programmatic requirements and the scale of the surrounding campus or community. Footprint areas of 20,000 to 30,000 gross square feet are not uncommon and have the potential to accommodate a number of research groups. Footprint widths of 80 to 100 feet are also not uncommon and provide sufficient dimensions for a variety of contiguous laboratory and laboratory support functions. However, academic campuses or surrounding residential neighborhoods may not have many multistory buildings with footprints of these dimensions. Therefore the scale of the surrounding campus and community should be considered when determining the building footprint.

Building Air Intake and Exhaust

The siting of a laboratory facility and the location of its air intake systems and exhaust stacks require careful consideration to minimize the possibility of contamination of the incoming air by neighboring buildings or activities, exhaust from vehicles on nearby streets, or exhaust from vehicles in the building loading area. The local prevailing winds as well as building exhaust and other sources of pollutants, such as vehicle exhaust, all need to be considered when locating the air intake for the building. Similarly, the location of the building exhaust must be considered to avoid contamination of neighboring buildings via their air intake, windows, or other openings. Equally important, the exhaust stacks must be located so as to prevent exposure of people outside the building to potential exhaust hazards. A more detailed discussion of the design considerations related to the fume hood exhaust system is provided below in this chapter.

Campus Interactions

In selecting the building site for a laboratory facility, planners should consider desirable campus interactions that should be encouraged and maintained. An academic or research campus is a dynamic environment where researchers in one building routinely interact with colleagues in other buildings. Interdisciplinary research is commonly promoted, encouraging chemists to interact with materials scientists and engineers, biologists to interact with agricultural scientists and environmentalists, and project teams to interact with academic and planning committees. In additional to collegial interactions, researchers interact with individuals who provide campus support services, which vary from campus to campus but may include machine shops, graphic arts, instrument repair shops, libraries, accounting offices, central stores, and many others.

In the predesign phase, a diagram of interactions is commonly developed to rate the relative importance of interactions between laboratory users and individuals or groups outside the laboratory building. The same approach can be used to rate different siting alternatives based on how each promotes or discourages important interactions; the siting of an addition or new building should consider and, if possible, support the interactions identified as most important. The location of entries to a laboratory facility as well as public and private amenities can all affect the interactions between building users and outside parties.

Access to the Building

The site of a laboratory addition or a new laboratory building must allow unrestricted access by people and vehicles. Access to the building itself must comply with the Americans with Disabilities Act (ADA) and other relevant laws and regulations. Because people will arrive by car, by bike, on foot, in wheelchairs, and by public transportation, provisions for dropping off and picking up people by car and requirements for access to public transportation all have to be considered.

Research is a 24-hour-a-day activity, and so the safety implications of providing 24-hour access need to be considered when a building site is selected. For example, a building located on the edge of a campus may be more accessible to visitors from outside the institution, but such access could possibly create a safety risk to building users, particularly at night. A building located in the center of a campus may reduce access for uninvited visitors and encourage interactions with other campus occupants but may also require visitors and users to walk from possibly unsafe perimeter parking lots day and night. The risks posed by the proposed building location, whether it is on a campus, in the center of town, or at any other location, need to be assessed as part of the siting decision. Once the site is selected, appropriate site lighting and accessibility features, such as ramps, should be designed to minimize risks, improve personal safety, and maximize access.

Access to a laboratory building by large vehicles, such as tractor-trailer trucks, is required for delivery and pickup of materials and supplies. Proper access to and design of the loading dock are also required for the safe handling of materials that may present chemical or biological hazards. Equally important, a laboratory building must be accessible on multiple sides by large fire protection vehicles and other emergency response equipment and vehicles.

Total Environmental Design Approach

Ultimately, the design and siting of a laboratory facility should incorporate a total environmental approach based on knowledge of all aspects of the building's function and environment. The issues include both natural and man-made environmental elements, as well as legal and regulatory requirements.

Floor Planning

The planning of the laboratory floor is influenced by the building's site, building and fire codes, security concerns, laboratory users, the culture of the organization, and other design decisions made during previous phases. The laboratory floor layout and the resulting traffic flow can reflect or change the culture of an organization. For example, the building can promote interaction by centralizing or clustering research offices and by locating conference rooms or other meeting spaces to allow ready access from the laboratories and offices, or it can isolate researchers by placing small, closed laboratories along a lengthy circulation corridor.

Interaction diagrams can be used as a method to identify desirable and undesirable interactions within the building as well as critical interactions between occupants of the building and the surrounding campus and community. These interactions should be considered when alternative floor layouts are evaluated to identify appropriate adjacencies.

In a corporate research facility, the research laboratories may need to be located in areas of the building that are not readily accessible to the general public. In that case, meeting rooms are needed so that visitors can interact with the building occupants without having to enter the secure area of the building. A reception area with adjoining conference rooms, augmented by the necessary security measures, is a common solution to the need for providing spaces accessible to invited guests while restricting access to other portions of the building. The building can be designed to clearly define the entrance and the areas within the building intended for use by the general public.

The design group can help the client develop a systematic approach to identifying intended interactions, security levels, and functions of the building. The planning of the various spaces on each floor should reflect the established interaction criteria.

Modular Approach to Laboratory Floor Layout

A modular approach to laboratory floor layout is generally recommended by design professionals and often used. The single laboratory module is the starting point for the floor layout. Larger laboratories, which can support group research activities, sharing of support facilities, and the larger area required for teaching laboratories, can comprise multiple laboratory modules. When a floor layout is modular, partitions to separate laboratory units can easily be added to the larger laboratory units to define space for different activities if the need arises.

The size of the laboratory module and the grid configuration are often determined at the same time—one typically informs the other. In turn, the number of modules and the grid configuration determine the overall size of the building footprint. The structural grid is defined by the structural column and beam locations. Thus for a building with a structural grid of 24 feet by 30 feet, a single laboratory module would typically occupy one-half of the width of the grid, or in this example an area 12 feet by 30 feet, or 360 square feet. The area of the laboratory module may be reduced, however, by the configuration of the circulation corridor. For example, the area of the laboratory module would be reduced to 12 feet by 24 feet if a 6-foot-wide peripheral circulation corridor were used. Mayer (1995) discusses typical laboratory module sizes and standard work area layouts for them.

Planning a floor layout by the modular approach and standardizing the sizes and shapes of the individual laboratories will create a flexible floor plan that is space efficient and less costly to construct than one with fixed assorted-sized laboratories. Developing a generic laboratory design with features that accommodate the majority of the researchers' requirements can also result in a highly efficient research laboratory facility. Customized configurations of the laboratory and its support spaces can be less flexible, less space efficient, and more costly to construct. Some customization, however, is necessary to accommodate the specialized requirements of individual research laboratories. On the one hand, customization in laboratory support spaces can provide necessary unique facilities without compromising the integrity of the generic approach to the research laboratories. On the other hand, inessential personal customization of research laboratories or laboratory support spaces can delay the progress of the design and documentation phases and escalate project costs. Highly customized laboratories limit the ability to move research activities from one laboratory to another, and highly customized features desired by one researcher may represent an encumbrance and safety hazard to other researchers. Minor changes to a generic laboratory are easy to accomplish at a modest cost, whereas changes to a highly customized laboratory can be costly.

Laboratories, Offices, and Support Space Adjacencies

The relationship of the laboratories, offices, laboratory support spaces, and other support spaces in a building is critical to the functionality of the building and the efficiency of the research facility. For instance, the functionality of the research facility can be maximized if laboratory areas are configured contiguously, and the efficiency of the research suite can be maximized if the laboratory support spaces are located adjacent to the research laboratories. But some laboratory facilities may require particular activities to be separated. For example, in a university environment, research laboratories are most often separated from teaching laboratories and classrooms. Teaching laboratories and classrooms that support introductory science courses may generate considerable pedestrian traffic, which can inhibit the movement of researchers, supplies, and equipment between laboratories and laboratory support spaces. Further, increased security problems may result if research laboratories are located adjacent to public access corridors. Other laboratory settings may require separation for technological reasons. For instance, researchers using vibration-sensitive equipment often need to be physically separated from those whose use of large motors or impact devices creates vibrations. And, as pointed out in the section "Environmental Health and Safety" above in this chapter, controlled access may be required for health and safety reasons.

Laboratories are the most expensive space in a research facility. They should be organized with appropriate proximity to laboratory support areas, storage space, offices, and building support areas in an effort to maximize the cost-efficient use of all spaces of the building. Laboratory support spaces, storage space, and, to the extent possible, offices should be designed to facilitate possible future conversion to laboratories. The modest increase in project costs incurred as a result of designing for this future adaptability will be saved many times over during the building's lifetime through savings in future laboratory renovations and minor alterations. Research laboratory buildings designed without adaptability in mind may require major renovation for a minor alteration to a laboratory as a result of inaccessibility to laboratory services or unavailability of appropriate space for expansion.

During the planning of the laboratory floor, researchers commonly request offices located adjacent to the laboratories. Decentralized offices located adjacent to and interspersed with laboratories allow researchers to circulate between office and laboratory with minimal effort. However, centralized offices may encourage researcher interaction. Further, because offices can use recirculated air, they can be served by a dedicated heating, ventilation, and air conditioning (HVAC) system if centralized. Laboratories, which in most cases cannot recirculate the exhaust air, can then be served by a separate HVAC system sized only for the laboratories. Using the less costly, recirculated-air HVAC system for offices and minimizing the size of the costly HVAC system serving the laboratories can reduce operating costs. Finally, creating laboratory zones composed of many contiguous laboratory modules is generally considered a more flexible arrangement than isolated laboratories because it allows research groups to grow and shrink without costly renovations to the space they occupy.

Laboratory support functions, including instrument rooms, equipment rooms, tissue culture rooms, glassware wash rooms, and storage rooms, are also often centralized in areas or zones. Sometimes laboratory support zones flank a central circulation corridor with research laboratories located on the periphery. In these instances, offices are often clustered and located at the corners of the laboratory floor to ensure that each office has an exterior window. This configuration also ensures that laboratories are adjacent to rooms housing laboratory support functions. Other configurations locate laboratory support spaces in a central zone separated from the peripheral laboratory zones by a racetrack circulation corridor. A service corridor may bisect this laboratory support zone. The various types of corridor configurations are more fully discussed below in this chapter, in the section on “Corridors.”

The size and location requirements for storage space—a laboratory support function—should be carefully considered, as should expectations for short- or long-term use. Appropriate and adequate storage areas should be included in the planning phases, particularly for storage of potentially hazardous chemicals that require unique environments. Supervision and management of the storage areas can be as critical as the provision of adequate, well-designed storage spaces and should also be considered in design specifications. Storage space should support the research and other activities within a laboratory building and should not be used to house defunct equipment or unusable chemicals.

Strategic design and use of storage areas, particularly those for chemicals, can have many safety, environmental, and health-related benefits, as discussed in the section “Dedicated Storage Space” in this chapter. Conversely, storage of chemicals and flammable materials in a laboratory can increase users’ exposure, increase the fire load in the laboratory, exacerbate a fire or other incident, and increase the cleanup cost after such an incident. Laboratory storage rooms should therefore be located adjacent to the laboratories they support and equipped with storage cabinets built to house flammable materials and ventilated cabinets for the storage of toxic and noxious materials. Equipment storage rooms should be included in the design of a laboratory facility to minimize the storage of unused equipment in the laboratory.

BOX 3.9 Common Floor Layouts

- Central circulation corridor
- Off-center circulation corridor system
- Peripheral or racetrack circulation corridor
- Peripheral or racetrack circulation corridor with exterior offices
- Central service corridor
- Open laboratory suite concept

Laboratory floors are often designed around building service cores that centralize building support areas such as stairways and elevators, utility shafts, communication equipment rooms, rest rooms, and other shared functions, such as MEP equipment.

Corridors

The layout of circulation corridors should support efficient access to all adjoining spaces and encourage interaction. It should also support efficient emergency egress as described in the "Environmental Health and Safety" section of this chapter. Long, uninteresting circulation corridors and circuitous circulation pathways can inhibit interaction of the building's occupants.

The arrangement of corridors in research laboratory buildings can take several different forms (see Box 3.9). The "central circulation corridor" layout has laboratories located on either side of the corridor. The "off-center circulation corridor" layout has laboratories on one side and offices or support spaces or both on the other. The "peripheral" or "racetrack" layout has a circulation corridor on the periphery with laboratories located in the interior of the building. A common variation on the peripheral circulation corridor layout has offices on the exterior of the building with the circulation corridor separating the offices and laboratories, which are then centrally located. A disadvantage of the peripheral or racetrack corridor design is the lack of natural light into and views out of the laboratories located on the interior of the building.

In larger laboratory buildings, service corridors and freight elevators are included in the design to facilitate the movement of supplies and equipment throughout the building without using the circulation corridors and elevators. Service corridors typically serve as pathways for deliveries and MEP systems and as limited storage areas for equipment. A service corridor that combines these functions may require a width of 12 feet and should include typical interior finishes on the walls, ceiling, and floors. A service corridor that serves a single function may require only a 6-foot width and may provide storage space for the adjoining laboratories for cylinders and limited supplies. Valves serving laboratory systems can be located in the service corridor, thus enabling access to service controls if repairs or an emergency shutdown are required. A service corridor may also provide a secure area for pickup and delivery of materials without requiring entry to the laboratories.

For floors configured with peripheral circulation corridors, the service corridor is typically located in the center of the building at the interface of two laboratory zones. For floors with a central laboratory support zone flanked by corridors in a racetrack configuration, the service corridor may bisect the laboratory support zone. The peripheral or racetrack corridor configuration typically results in a building with a footprint exceeding 100 feet. Research laboratory buildings with footprints of this width, though not uncommon, often require careful consideration during the site selection process as discussed above.

Traffic Flow

A laboratory building is a dynamic environment. Hundreds of people from different professions use the building and maintain the operating systems and equipment. These people include researchers, technicians, students, customers, secretaries, and maintenance staff, at a minimum. Specialized service technicians are also needed to keep both the building and the instruments and computers within the building in good operating conditions. The ability of these various individuals to move as required throughout the laboratory facility needs to be considered during the design phases of a renovation or construction project.

The flow of supplies and equipment throughout the building also needs to be seamless. Special considerations are needed to address the quantity, size, and weight of supplies and equipment moved within the building. Large instruments such as NMR spectrometers, mass spectrometers, and laser optics tables, and equipment such as mixers, extruders, walk-in refrigerators, and ovens are used in a typical laboratory building. Other large items such as gas cylinders, cryogen cylinders, and photocopiers also are moved through a laboratory building.

The people, equipment, and supplies all need to enter and move smoothly within the building. Entrances for people should be separate from loading docks for receiving supplies and equipment. Inside the building, people and supplies may share circulation corridors and elevators or, in larger buildings, separate freight elevators and delivery service corridors may be provided. While corridors must be designed to optimize the flow of people, equipment, and supplies, they should also be carefully designed to discourage inappropriate uses, such as storage of equipment and supplies.

In addition to the various users and occupants noted above, chemicals, supplies, instrumentation, and furnishings will need to be safely and efficiently transported to and throughout the building. Safe and appropriate paths for hazardous and nonhazardous materials should also be considered during the design phase. Some building and fire codes restrict or prohibit the transport of hazardous materials in circulation corridors, requiring noncirculation corridors for such use. Corridor and door widths and elevator cab sizes and capacities should all be considered with these special needs in mind during the design process.

Access

Points of access to research laboratories, teaching laboratories, and laboratory support areas have to accommodate people and also large, bulky, and potentially hazardous materials. Large items require wide corridors, wide doors, large elevators, and specially designed corners to permit a wide turning radius. Transporting extremely heavy items within a building may be restricted or even prohibited if the building was not designed to support extremely heavy loads. If only part of the building is designed to support extremely heavy loads, the circulation corridors and elevators used to access that part of the building must also be designed to support the heavy loads.

A 36-inch-wide door is standard for laboratories and laboratory support areas; however, commonly used laboratory equipment and large instruments may require a wider door opening. Door widths of 42 or 48 inches should be considered in these instances. If a single door leaf of 42 or 48 inches is heavy, it may require special hardware to meet ADA access requirements. Double doors could also be used, but a common solution is to use two doors of unequal width. Typically a 36-inch door, called the active leaf, is used with an 18- to 24-inch door called the inactive leaf. The 36-inch door, the minimum size required to comply with ADA requirements, is used on a daily basis to access the laboratory. The smaller door can be opened easily in the infrequent instances when the extra width is needed to move a large item into or out of the laboratory.

For similar reasons, corridors 6 feet wide or wider are common in research laboratory facilities. Narrower corridors do not permit the movement of large items and can obstruct the bidirectional flow of traffic. Even corridors 6 feet wide may not provide a turning radius sufficient for some large items to turn a corner through a door along the corridor.

Elevators pose similar problems. The width and height of the elevator doors, the size of the cab, and the capacity of the elevator all are critical to the efficient movement of large and heavy items throughout the building. Where large pieces of equipment must be moved, high ceilings and doorways are required. Corridors often must have ceiling heights greater than 8 feet. The movement of tall apparatus may require doorways taller than 7 feet. These standards, regularly used for other building types, should be reexamined when planning a research laboratory facility. Corridor ceiling heights of 9 or 10 feet and door heights of 8 or 9 feet may be required in parts of a building where large equipment is used and moved.

The entry to the building and the pathways within the building for movement of large equipment start at the loading dock and must be clear of any low obstructions. During the lifetime of a building, large pieces of equipment will need to be replaced in the building equipment rooms, and provisions for their replacement should also be included in the initial design of the building.

Egress

Laboratory egress requires all the physical specifications detailed above in the section on "Access" but is also regulated by codes. Dual egress—i.e., two exits—for all laboratories is often required by fire and building codes, and dual egress for other areas is often encouraged. Storerooms or laboratory preparation areas with flammable materials, water and electrical hazards, and chemical hazards should also have dual egress. In addition, there must be a continuous and unobstructed path from any point in the building to an outside exit. This requirement is further discussed in the section "Environmental Health and Safety" in this chapter.

Special Features

Atrium. An atrium can make a strong statement about the ideology of the research laboratory facility. An atrium can serve many functions, such as a reception area, a meeting area, or an opening to bring daylight into the center of a large building. However, atriums can create additional ventilation requirements as a result of additional solar gain or code-mandated smoke evacuation systems. Shading or filtering the solar gain in the atrium can minimize the additional ventilation requirements. An atrium in a laboratory building can create additional complications associated with the balancing of the HVAC system. A proper evaluation of the advantages and disadvantages of an atrium should be completed during the design phase.

Loading Dock. The loading dock is the primary point of entry for supplies and equipment to the building. In addition to an area for receiving and shipping goods, the loading dock is also a staging or collection area for a laboratory building. Many laboratory buildings have storerooms, gas cylinder holding areas, waste collection facilities for both office and hazardous laboratory wastes, storage facilities for flammable materials, and refrigerated storage all located adjacent to or easily accessible to the loading dock. Once the materials are in the building, the network of corridors and elevators must support their safe transport throughout the building. Factors determining the location of the loading dock have been considered in the "Building Air Intake and Exhaust" and "Access to the Building" sections of this chapter.

Elevators. Elevators facilitate the safe movement of people and materials throughout a building. Elevators are needed even in a two-story building to move large and heavy items between floors and to comply with ADA requirements for accessibility. In a smaller building, a single elevator may serve for both passengers and freight. A larger building may have passenger elevators accessible from the main pedestrian entrance and separate freight elevators accessible from the loading dock and the service areas.

In a laboratory building, larger elevators with increased capacity may be needed to move the large, bulky, and heavy equipment and supplies throughout the building. Entry areas adjacent to elevators need to be sized to permit large items to easily be loaded into and unloaded from the elevator. If an elevator opens directly into a 4-foot-wide hall, the turning radius may not be sufficient for loading the elevator with large equipment.

Materials Distribution. Larger quantities of materials and supplies are moved within a laboratory building than in an office building. Orderly movement of the materials is accomplished by a well-designed network of hallways, service corridors, elevators, and a loading dock with adjacent areas for receiving, storage, and staging. In larger buildings, a dedicated network of service corridors and freight elevators can be used to minimize the congestion in the pedestrian circulation corridor and passenger elevators of the building. Service corridors with designated freight elevators provide an additional margin of safety for the building users. People using pedestrian circulation corridors are physically isolated from the movement of large, heavy, bulky, and potentially hazardous items through the service corridors. The delivery personnel, using the service corridors, can focus their attention on their task and are less likely to be distracted or startled by a person stepping out of an office into the path of an oncoming, fully loaded delivery cart.

Security. The building design, especially the means of access and egress, should take personal security and the need to protect property from theft into consideration.

Laboratory Configuration

A laboratory with fume hoods, benches, and a sink may be the generic image of a laboratory, but the specific needs of different laboratory activities or scientific disciplines require highly specialized facilities (see, e.g., DiBerardinis et al., 1993, pp. 123-342). In general, research laboratories require special ventilation, are utility intensive, and require special furnishings that can withstand instruments, equipment, and potentially caustic and damaging chemicals. In chemistry laboratories, a fume hood usually provides the special ventilation needed. In molecular biology laboratories, high-efficiency particulate air (HEPA) filters and biosafety cabinets may be required to meet the special ventilation requirements. These and other features (Box 3.10) of laboratories and many of the related issues that must be considered when designing a laboratory are discussed in this section.

BOX 3.10 Laboratory Features and Furnishings

- Laboratory desks
- Fume hoods
- Special ventilation
- Laboratory casework and furniture
- Laboratory utility services
- Bench tops
- Flooring
- Lighting
- Accommodation of special environments

The modular approach to laboratory floor layout is discussed above in this chapter. It is often more cost-effective to also use standardized laboratory design throughout the laboratory modules for layout, utilities, furnishings, and other features. The standardized or generic laboratory design can be modified to accommodate specific research requirements. Necessary modifications are those that enable laboratory occupants to do their work safely and efficiently.

Laboratory Desks

The location of desks for researchers and support staff should be determined based on considerations of safety and efficiency but should also reflect institutional or departmental preference. The extended exposure of laboratory occupants seated at desks to chemical and other laboratory hazards and the common occurrence of eating food at desks are the most frequently given safety-related arguments against desks in the laboratory. The consumption of food and beverages should be strictly prohibited in laboratories where any hazardous materials are used and can be discouraged if the laboratory floor layout includes lounges designed for eating, drinking, and interaction (NRC, 1995, pp. 82, 94). Previously, smoking was an additional argument against desks in the laboratory, but as a result of changing social practices smoking has been banned in laboratories and in many buildings.

Locating desks for researchers and staff in the laboratory is generally more area-efficient than locating desks in adjacent shared offices. In addition, researchers seated at desks in the laboratory are able to closely monitor the progress of ongoing experiments. Alternatively, some institutions require that the laboratory floor be planned with adjacent shared offices rather than desks in the laboratory. Windows in the wall separating the shared offices from the laboratory allow researchers in the adjacent offices to monitor laboratory activities.

Laboratories with adjoining shared offices may be more difficult to expand for larger research groups without expensive renovations. However, researcher and staff interaction may be encouraged when desks are located in a shared office.

Fume Hoods

Laboratory fume hoods are costly to purchase, install, and operate, but for chemistry laboratories, fume hoods are essential for laboratory safety. Fume hoods are necessary for most chemical research activities, and the use of personal fume hoods in academic chemistry teaching and research laboratories is becoming more common. Many academic institutions believe that both undergraduate and graduate students should be trained in the proper use of laboratory fume hoods. The safety aspects of the hoods are discussed in "Environmental Health and Safety" in this chapter.

In many research disciplines, the area covered by the fume hood is the primary location of all laboratory experimentation. The primary function of the fume hood is to protect the researcher and other building occupants from the hazards of the experiment. Proper selection of the fume hood features and proper design of the entire HVAC system are required for the fume hood to function properly and to provide the protection for which it was installed.

Many features of a laboratory fume hood should be considered when planning a research laboratory (see Box 3.11). The research to be conducted in the fume hood, as well as environmental, fire protection, and safety issues, must all be considered when specifying a laboratory fume hood.

Performance. A discussion of the aerodynamic design of a laboratory fume hood cabinet is beyond the scope of this report and is best left to the fume hood manufacturer. Manufacturers typically specify a fume hood face velocity for optimal performance of their products. Face velocities of 90 to 100 feet per minute (fpm) are typical but can range from 60 to 120 fpm. The capabilities of a building's HVAC system will dictate whether the specified face velocity is obtained and can be maintained. Face velocities too high or too low are detrimental to safety and to the performance of the fume hood. Fume hoods with too high a face velocity are also less energy efficient, which contributes to higher operating costs.

Fume Hood Utility Services. In addition to air supply and exhaust systems, many other utilities typically required for experimentation must be readily available in the fume hood. Typical utility services include running nonpotable wa-

BOX 3.11 Features of a Laboratory Fume Hood

- Performance
- Utility services
- Dimensions
- Sash type
- Base cabinets
- Construction materials
- Location in the laboratory
- Special characteristics

ter, laboratory waste removal, electric outlets, and lighting. Other utility services can include the supply of natural gas, compressed air, nitrogen, argon, vacuum, steam, and chilled water as discussed in the section "Building Services" below in this chapter. As with the design of generic laboratories, it is advantageous to standardize the design of the fume hood used in most research laboratory facilities that require numerous hoods.

Dimensions. Common exterior widths for fume hoods are 4, 5, 6, and 8 feet with 5 and 6 feet the most commonly requested lengths. The standard exterior depth is 3 feet with an interior depth of about 30 inches. Larger fume hoods are more expensive to operate because of the increased volume of air needed to maintain the specified face velocity. Fume hoods less than 5 feet long can be confining and difficult to use. Some small, narrow, custom-designed fume hoods are used in academic teaching laboratories where laboratory space is at a premium. Fume hoods more than 6 feet long allow researchers to set up more than one experiment in the fume hood or use part of the fume hood for storage. Both practices are forms of misuse that may create a hazardous situation and may increase the potential for an accident. Some academic and corporate laboratories, particularly those whose work involves synthetic and organic chemistry activities, require that each researcher be provided with an 8-foot-long fume hood.

Sash Type. Vertical, horizontal, and combination fume hood sashes are commonly used and are typically composed of tempered glass. A vertical sash is guided up and down in track rails attached to the hood and to the sash sides. The weight of the sash is balanced with counterweights in the back of the fume hood. Periodic inspection and adjustment are needed to maintain an easy, effortless movement of the sash. Horizontal sashes consist of multiple panels, with or without frames, which slide independently and horizontally in tracks at the top and bottom of the sash. Some fume hoods are designed to allow the horizontal sashes to be easily removed, reducing obstructions during experiment setup. In a combination sash, the panels of a horizontal sash are mounted in a vertical sash frame. The sashes can be moved in a horizontal direction as in a horizontal sash, and the frame can be moved up and down as in a vertical sash. The cost of sash type increases from vertical to horizontal to combination. Fume hoods with horizontal sashes generally require less air to maintain the specified face velocity because of the smaller opening created by the multiple panels. These fume hoods are therefore generally less costly to operate. Fume hoods with horizontal sashes, when correctly used, provide a safety barrier of tempered glass for the researcher reaching around the centered panels. However, some researchers find the horizontal sash fume hoods awkward to use correctly and often remove the sash panels or slide them up if combination sashes are provided.

Base Cabinets. Storage cabinets for flammable solvents and for acids are commonly placed beneath the fume hood, a convenient location because the solvents and acids are routinely dispensed in the fume hood. In addition, such storage cabinets frequently require connection to the exhaust air system. Base cabinet drying ovens are occasionally used but may pose a safety risk because of the location of a heat source in an area where flammable-solvent vapors may be present. Fume hoods with no base cabinets may be used to comply with ADA requirements.

Construction Materials. Fume hood construction materials should be selected for durability and suitability for the required task. The construction materials, types of finishes and surfaces, and the type of research all need to be considered. Epoxy-coated metal is typically used for fume hood and base cabinet enclosures. Nonferrous fume hood enclosures are also available for specialized research applications. The interior cabinet enclosure is typically made of an inert, nonflammable, nontoxic, synthetic material. The working surface is typically molded epoxy resin or stainless steel.

Location in the Laboratory. Although experts may disagree on the best location for a fume hood in the laboratory, all agree that the fume hood should be located so as to minimize researcher movement in front of the fume hood. The movement of people and equipment creates eddy currents of air, which decrease the efficiency of the fume hood and can expose the passerby to potentially harmful vapors drawn from the fume hood. Fume hoods should be located away from doors because doors also can create eddy currents. In the event of an accident in the fume hood, one located by the door could block the primary path of egress from the laboratory. A dual-egress design for all laboratories can minimize this problem.

Face-to-face configurations of fume hoods should be avoided due to complex air currents that may be generated by two opposing fume hoods. If a face-to-face arrangement is required, the minimum dimension separating the fume hoods should equal the length of the fume hood but should not be less than 5 feet. Fume hoods should be located as far from researcher desks as is reasonably possible. Beneficial air currents can be created if makeup air (for description see “Exhaust and Makeup Air” below in this chapter) is delivered at the end of the laboratory opposite the fume hoods.

In some research disciplines and for some laboratory activities, such as solvent distillations, researchers prefer that the fume hood be isolated in a room separate from the primary laboratory.

Special Characteristics. Many different, highly specialized fume hoods, such as explosion proof, corrosive resistant, or with filtered exhaust, are manufactured either on a routine or custom basis. Special fume hoods are required when working with radioisotopes, perchlorate, and pathogens. Height-adjustable fume hoods without base cabinets are available for ADA compliance.

Ductless Fume Hoods. Many academic institutions are investigating and starting to use ductless fume hoods in their undergraduate teaching laboratories. Technically, they are not fume hoods because they do not exhaust air from the enclosure to the outside. There is currently insufficient information to recommend them as substitutes for ducted fume hoods (NRC, 1995, p. 185).

Special Ventilation Devices

The laboratory fume hood is the most commonly used device for removal of odors and vapors from a laboratory building, but other devices are also used. Canopies are used to ventilate odors from weighing activities at a balance, ozone and other toxins from plasma emission spectrometers, and excess heat from an oven or other equipment. The exhaust from many instruments, such as gas chromatographs and atomic absorption instruments, should be exhausted from the laboratories. For many instruments, the exhaust venting can be accomplished with a small flexible duct from the instrument to a larger building or fume hood exhaust duct. Numerous special ventilation requirements of instruments and common laboratory activities are frequently overlooked in the planning and design of laboratory facilities.

Laboratory Utility Services

Utility services must be provided to each laboratory. These are discussed in detail in the section "Building Services" below in this chapter.

Laboratory Casework, Furniture, and Bench Tops

Laboratory casework includes cabinets of various configurations above and below the laboratory bench. Casework comes in several different types including built-in, modular, and freestanding. Built-in cabinets below the laboratory bench typically support the bench top. Modular casework is constructed as a system of modular units typically composed of a supporting frame that independently supports the laboratory bench, upper and lower bench cabinets. Some modular casework systems also integrate the laboratory services. A ventilated reagent cabinet adjacent to a hood can be substituted for similar under-hood cabinets. The modular design has a slight initial cost premium but provides substantial savings for organizations that frequently reconfigure laboratories. The modular system allows bench heights to be changed from a standing (36 inches) to a sitting (30 inches) height without major renovations. Base cabinets can also be changed without major disruption to the laboratory.

Laboratory furniture includes freestanding tables, desks, and file cabinets that are not physically connected to the building and do not have built-in services. Furniture can also include rolling base cabinets that can be put under fixed casework or freestanding tables. For laboratories with the services mounted on the wall or on superstructures, conventional freestanding furniture can provide laboratory flexibility at a minimal cost.

Laboratory casework, furniture, and bench tops come in a broad range of quality and materials of construction. Commonly used materials include wood, metal, plastic laminates, and combinations of these types. Within each type of material a broad range of quality is available. Selection of the type and quality of material is determined by the image the institution wants to project, the type of research conducted in the laboratory, the anticipated useful life of the laboratory, the frequency of renovations, and the project budget available for laboratory furniture. Corrosives can damage the finish and material on a metal cabinet and decrease its useful life. Many laboratories require surfaces that are nonporous and easily cleaned, disinfected, and decontaminated. In these situations, metal or laminates are preferred. Solvent resistivity of materials and finishes should also be considered in selecting laboratory furnishings.

Flooring

The selection of the laboratory flooring should be based on the type of laboratory and the scientific discipline. The flooring should be easy to clean and maintain; it should prevent water penetration and withstand damage from harsh chemicals such as strong acids and caustic and organic solvents. If damaged, the flooring system should permit simple repair or complete replacement. Seamless vinyl, epoxy coatings, or painted concrete are commonly used laboratory flooring materials. Antislip and antistatic mats, pitched floors, and gratings may also be required in special situations.

Lighting

Lighting design is a specialty in itself. Lighting in laboratories, offices, and other interior spaces; control of ambient light; emergency lighting; and illuminating the outside of the building at night all require care in their design, installation, and operation. Lighting levels of 80 to 120 footcandles are common in laboratories and typically exceed lighting levels in other building types such as office buildings. A significant portion of the electricity consumed in a building goes to lighting. Energy-efficient lighting products should be considered, and local power companies may offer incentives for their use. The expertise of a lighting design specialist is required for most laboratory construction and renovation projects.

BOX 3.12 Building Services and Structure

Services
- Utility distribution
- Exhaust and makeup air
- Heating, ventilation, and air conditioning
- Fume hood exhaust
- Laboratory and fume hood services
- Special electrical power requirements
- Communications and data equipment

Structure
- Structural grid
- Vibration
- Floor loading

Accommodation of Special Environments

The list of highly specialized laboratory requirements is endless and varies by discipline. Some commonly encountered requirements include radio frequency shielding, magnetic shielding, isolation from vibrations, constant temperature, humidity control, and particulate control. In general, accommodating these specialized needs is costly, and satisfying a specialized need on a case-by-case basis is more cost-effective than trying to satisfy the need universally throughout the building.

Building Services and Structure

The building services, the configuration of the mechanical, electrical, and plumbing services and equipment, and the structural system (Box 3.12) are typically determined in the design phase.

Building Services

Laboratory buildings require robust HVAC systems to handle the additional demands placed on the equipment by laboratory fume hoods. In addition, building services may include laboratory-grade, potable, nonpotable, and cooling water; laboratory and sanitary waste removal; and the supply of natural and specialty gas, vacuum, and other specialized services. Many laboratories require special electric services; their electrical circuit breaker panels need to be in the laboratory or immediately adjacent to it. All utility shutoffs need to be easily accessible and strategically designed so that service to localized areas, such as a laboratory or a wing, can be shut down for routine maintenance, for renovation, or in an emergency. Seemingly minor incidents in a laboratory building can have significant financial consequences for want of a readily accessible service shutoff. For example, if a water pipe breaks and water runs for several hours, it may cascade through several floors of a building, damaging ceilings, flooring, wall finishes, and scientific equipment. Water damage, electrical fires, and flammable gas leaks can easily be prevented with strategically placed shutoff valves. The services to each laboratory and to each wing or floor should be isolated and easily shut off. Small laboratory installations, maintenance, or minor repairs become major incidents when the entire building must be shut down to change one washer in a valve that would not close. Shutoffs on deionized water systems are commonly overlooked.

Utility Distribution. Utility chases and interstitial spaces are used to distribute utility services throughout a building. Since laboratory buildings are much more utility intensive than are office buildings, routing the utilities throughout the building is more difficult.

Use of interstitial spaces can simplify utility distribution in a laboratory building and can provide greater flexibility over the building's lifetime. Housing utility services and equipment between occupied floors permits routine maintenance and modification with minimal disruption of the activities of laboratory users. Designing a laboratory building with interstitial space may significantly increase the construction cost, but that cost likely will be recovered over the lifetime of the building through decreased maintenance costs, decreased cost of modification and renovation, and decreased disruption of the primary activities for which the laboratory building was built.[3]

Utility chases for ventilation ducts, plumbing, and electrical services can run vertically or horizontally, in a wall or along the ceiling. When distributed at the ceiling, ducts and pipes can be left exposed as an intended design element or concealed with a drop ceiling. Servicing or modifying utilities distributed at the ceiling will frequently disrupt the activities of the laboratory staff and other building users.

Box 3.13 lists a variety of locations for placement of utility chases. A utility service corridor, which is very much like an interstitial space except that it can be horizontal or vertical, is a passage within the building with utilities running along its walls either vertically or horizontally. A horizontal utility service corridor is for use by building maintenance personnel and is not intended as a circulation corridor for other building users. DiBerardinis et al. (1993) includes an

[3]Reported in presentations to the committee by P. Richard Rittelman, Burt Hill Kosar Rittelman Associates, April 13-15, 1998.

BOX 3.13 Options for Location of Utility Chases Within Laboratory Buildings

- Utility service corridor
- Rear laboratory wall
- Exterior wall
- Corridor wall
- Between laboratory modules
- Central utility shaft
- Central shaft in service core

extensive discussion of the advantages and disadvantages of the different approaches used for locating utility chases within a building.

Exhaust and Makeup Air. Laboratory fume hood operation is dependent on large quantities of air exhausted at high velocities. Laboratory makeup air is required to maintain the code-required balance between negatively pressured laboratories and positively pressured corridors. Ideally, makeup air is introduced to the laboratory at the point farthest from the fume hood, thus allowing for an efficient airflow and "flushing" of the laboratory. Makeup air can also be introduced through a perforated ceiling plenum. Air intake locations should be carefully chosen to prevent cross-contamination by exhaust air. The design of laboratory airflow requires consideration of the whole airflow balance within a building.

Heating, Ventilating, and Air Conditioning System. Many contemporary research laboratory facilities are designed to use variable-air volume (VAV) or constant air volume (CAV) HVAC systems. The VAV system uses sensors of various types, installed in the fume hood cabinet, exhaust duct, or sash guide rails, that indicate the amount of supply and exhaust air required to maintain a constant face velocity and a safe working environment in the fume hood. Valves controlled by a microprocessor connected to the sensors are installed in the laboratory air supply and exhaust systems; they regulate the amount of air entering and leaving the laboratory and maintain a constant face velocity at the fume hood as the position of the fume hood sash is changed.

VAV HVAC systems are generally more energy efficient and less costly to operate than other ventilation systems. The higher equipment cost, associated primarily with the need for numerous valves and sophisticated microprocessor controllers, is partially offset by the need for smaller air supply and exhaust fans. These fans can be smaller because, typically, only some of the fume hoods will require the maximum amount of air; others will demand lesser amounts. Each university or corporate laboratory must determine the appropriate relation for its installation. Because of this variable demand, the size of the HVAC supply fans and fume hood exhaust fans can be smaller, which results in both lower project costs and operating cost. However, some experts caution against assuming less than 100 percent maximal usage.

Other fume hood makeup air systems are based on a CAV system that maintains constant supply and exhaust air volumes. These fume hoods, often called bypass fume hoods, are designed with a louver that is exposed when the fume hood sash is closed and that is blocked when the fume hood sash is opened, thus maintaining a constant opening for exhaust air regardless of the sash position. A CAV HVAC system using bypass-type fume hoods may be less costly to install and maintain but is less energy efficient than a VAV system.

Fume Hood Exhaust System. Fume hood exhaust ducts should be made of a corrosion-resistant material, such as stainless steel. Lower grade, less costly materials such as galvanized metal with various coatings have not proven to be as successful for long-term application. Although the initial use of the fume hood may not involve corrosives, the research laboratory's requirements may change over time. The projected savings from using a lower grade material may not justify its use when the future costs of replacement and disruptions to laboratory activities are considered. Some research institutions have chosen to use galvanized exhaust ductwork where ductwork is exposed and stainless steel where ductwork is concealed.

The fume hood exhaust system can be designed as a single exhaust stack or as multiple exhaust stacks. Traditionally, a single exhaust fan and stack served each fume hood in a building. In large laboratory buildings, it was not uncommon to have hundreds of exhaust stacks extending through the roof. Each roof penetration represented a potential hazard in terms of both the exhaust and the possibility of water damage. Routine maintenance of such a roof was difficult because of the potential for exposure to exhaust. With the individual exhaust stacks occupying a significant portion of the roof, rooftop locations for air intakes were limited.

Current building codes mandate the height of the exhaust stack above the roof to minimize potential exposure to the stack exhaust. In modern laboratories, the exhaust from many fume hoods, if not all the fume hoods in the building, is combined in one or more large manifolds. These manifolds may exist as a horizontal duct on each floor, as a vertical duct or riser connecting all floors, or as a single manifold in the penthouse or on the roof. Large exhaust fans serve these exhaust manifolds, and the exhaust exits through one or more stacks often extending 12 to 20 feet above the roof. On many large systems, a second exhaust fan is installed on a single manifold to provide a backup fan, should the primary fan fail or be shut down for maintenance.

A system of manifolds and central exhaust fans has numerous advantages over the traditional design of a single exhaust fan for each fume hood. The maintenance, or balancing, of the relative air pressure in laboratory and nonlaboratory spaces is critical in laboratory buildings. Balancing air pressure in a system with exhaust manifolds, thus allowing the use of fewer exhaust fans, can be easier than balancing air pressure in buildings with hundreds of exhaust fans. Further, the initial equipment, installation, and operating costs are lower for manifolded exhaust systems than for traditional one-fan-per-fume-hood systems. The manifolded exhaust system is safer to operate because the exhaust stack and the building air intake can be separated more easily to minimize the likelihood of exhaust entrainment. It is more efficient in dispersing the stack exhaust because of increased dilution, increased velocity, and a larger air mass. (The manifolded exhaust system increases dilution because a number of fume hoods are vented simultaneously and additional air is introduced to allow the fan to operate constantly at a higher speed, hence a higher velocity. The increased air mass is created by the number of fume hoods served as well as by the additional exhaust air.) The increased velocity and mass allow the exhaust to be dispersed more effectively and to be less affected by wind. The centralization of exhaust stacks in a manifold also has the advantage of allowing for the installation of monitoring systems should they be required in the future, as discussed in the section "Controlling Chemical Vapor Emissions" earlier in this chapter. Further advantages and disadvantages of manifolded fume hood exhausts versus a fan per hood are discussed in *Prudent Practices in the Laboratory* (NRC, 1995, pp. 192-193).

Laboratory and Fume Hood Services. The concept of generic laboratory design discussed in the section "Modular Approach to Laboratory Floor Layout" above in this chapter can also be applied in providing services for both the laboratory bench and the fume hood, which typically require similar kinds of services. Wet services can include nonpotable hot and cold water, laboratory-grade water, chilled water or glycol, and waste removal connections. Safety-related services include potable tempered water serving eyewash and emergency shower fixtures. The laboratory-grade water may be produced by distillation, deionization, reverse osmosis, or a combination of these techniques. Air and gas services could include compressed air, natural gas, specialty gases, and vacuum. The list of specialty gases can include nitrogen, hydrogen, argon, helium, and propane. Special regulations apply to many of these gases, such as hydrogen and combustible gases. Electrical services could include outlets of various voltages and voltages controlled by rheostats. Other electrical services often include data and telephone connections.

Specialized laboratory and fume hood services needed by only a few laboratories should be provided on a case-by-case basis. For instance, central vacuum services can be costly. Water aspirators can be used but have some drawbacks and are banned by many institutions. As an alternative, vacuum pumps could be provided. They have a modest initial cost per installation; however, they require cold traps in most applications to condense potentially harmful vapors and to protect the pump, and they require routine servicing and oil changes. Used vacuum pump oil is hazardous and should be disposed of properly. A decision thus must be made about whether or not to install an expensive central vacuum system for an entire building or use an alternate. For some disciplines, the cost can be justified. Similarly, specialized gases can be provided from individual cylinders equipped with regulators. Chilled water or glycol can be provided by individual refrigerated circulating bath units.

Several different approaches are used to distribute services within a laboratory. Hardware delivering laboratory services is commonly mounted on the bench superstructure for island benches and on the wall superstructure for wall benches. Laboratory service drops from the ceiling can be contained in service chases to minimize visual clutter in the laboratory. When services are mounted on a metal frame superstructure that is independent of the laboratory benches, services and laboratory benches can be independently installed and dismantled. Distributing services from the ceiling typically provides a greater degree of flexibility since modifications or repair need only involve the laboratory being modified or repaired. Distributing services from the floor will require numerous penetrations of the floor, creating the potential for leaks from a laboratory above.

Penetrations through the laboratory floor should be restricted to laboratory waste lines and floor drains to reduce the potential for water and hazardous chemicals leaking from one laboratory onto the spaces below. Floor drains are recommended in most chemistry laboratories because of the potential for flooding caused by many sources of water.

Many types of laboratories, such as instrument laboratories, have extensive electrical power requirements. A modern laboratory typically has six or more 20-amp/120-volt circuits and several circuits require ground-fault interrupters; these are often best supplied by a dedicated electrical panel for each laboratory. Dedicated panels minimize the likelihood that the electrical service to a neighboring laboratory will be turned off by mistake. Higher voltages, such as 220 or possibly 440 volts, should be available at the panels for each laboratory. Some pieces of laboratory equipment may require higher voltages or three-phase current. Other requirements for uninterruptible power, emergency lighting, and backup power are pointed out below in "Special Electrical Power Requirements."

Special Electrical Power Requirements. Laboratory buildings have special requirements for power to protect people, property, and the environment in addition to those, such as emergency lighting and ground-fault interrupter circuits, common in any public building and specified by code. Special requirements include conditioned power or uninterruptible power to protect sensitive instruments and computers, maintain heating or cooling for critical experiments, and permit long-term experiments to continue through even brief periods of power interruption. Conditioned or uninterruptible power can be provided universally throughout a laboratory building via special circuits or can be handled on a case-by-case basis where smaller, local equipment is used to provide the special power at a single location. Another option is to locate all users with similar requirements in the same part of the building and provide the service in that one location. Providing conditioned and uninterruptible power is costly. The requests, as articulated by the building users, should be scrutinized to ensure their legitimacy.

Laboratories that use highly toxic materials require emergency shutdown capabilities in the event of an electrical power failure. Some designers have opted to install emergency power backup to the fume hoods used for these applications. Emergency power may also be needed to operate the exhaust fans for these specialized fume hoods. In a building with a manifolded exhaust system for fume hoods, substantial power is required to operate the central exhaust fan, and the supply fan must be operated simultaneously to maintain a positive pressure differential between the building and the fume hoods. Using emergency power to maintain the operation of the fume hood exhaust (and possibly the building supply) during a power outage can be costly.

Communications and Data Equipment. A centrally located, secure room on each floor is needed for the communications and data equipment for telephones, computers, and instruments in a laboratory building. The space should be easily interconnected with other equipment rooms in the building and with the service entry. Information technology and communications specialists should be consulted about room design and equipment installation. The room should be ventilated to remove heat generated by the equipment and will require conditioned electrical power and emergency power for lighting and possibly powering the information technology and communications equipment. Because technology changes rapidly, the building should be designed for adaptability to ever more modern communications. Networking and communications wiring and possibly fiber-optic links should be an integral part of the design and construction of any laboratory building. Prewiring the building during construction is essential for a cost-effective installation and smooth occupancy of the building. Wiring and communications equipment should be installed so that it is accessible for repairs, upgrades, and replacements.

Building Structure

The laboratory building structure should be designed to promote flexibility and adaptability. The structural grid should be sized to support contemporary research laboratory modules. The structure should be sufficiently strong to safely support heavy instruments or a large number of medium-weight instruments. Vibrations transmitted through the building should be minimized so as not to restrict the performance of vibration-sensitive instruments.

Structural Grid. Modern laboratory buildings are built with a structural grid that is often 22 to 24 feet wide by 25 to 30 feet long. A typical floor-to-floor height is 14 to 16 feet without an interstitial space and 20 feet with an interstitial space (Mayer, 1995). Vibration problems are common in buildings with grid lengths longer than about 30 feet. The width of the grid dictates the width of a laboratory module. A width of 22 to 24 feet is divided in half to make a laboratory module (or bay) of 11 to 12 feet. The use of the laboratory module to design the layout of the laboratories is discussed in the section titled "Modular Approach to Laboratory Floor Layout" in this chapter. The traditional laboratory module width of 10 feet may be too narrow for some research activities, especially in instrumentation laboratories. The wider grid provides greater flexibility in laboratory design and for future renovations.

Floor Loading. Some instruments and research equipment are heavy, and their weight exceeds the floor loading of many buildings. Some commonly encountered heavy equipment is listed in Box 3.14. Laboratory buildings should be designed with floor loading of 100 to 150 pounds per square foot to meet both current and future needs.

Frequently, various pieces of equipment require additional floor loading support. Several options are available to address the problem: place the equipment on the ground-level floor grade, strengthen several of the lower floors, or strengthen a wing or defined area of the building. A common problem with the last option is that the defined area of the building will support the equipment, but the circulation corridors and elevators in the building will not have been designed to support the weight.

Placing the heavy equipment at ground level has several advantages: little or no additional building stiffening is required, on-grade equipment is in a low-vibration zone of the building, and elevators do not need the higher load capacity.

Heavy equipment is usually large and bulky, thus requiring wider halls and doors and corners with a wide turning radius. If such equipment is kept in a designated area, then standard-dimension halls and doors can be used in the remainder of a laboratory building for a saving of space and construction costs.

BOX 3.14 Commonly Encountered Heavy Equipment and Instruments

- Nuclear magnetic resonance spectrometers
- Mass spectrometers
- Large number of medium-weight instruments
- Extruders
- Freezers and refrigerators
- Optics and laser tables
- Incubators
- Fabrication equipment

Vibration. Some instruments, such as NMR spectrometers, laser and optics tables, and electron microscopes are susceptible to vibrations, which can limit their performance capabilities. Some common sources of vibration include elevators, large motors such as those in air handler fans, and nearby road and train traffic. Some instruments are sensitive to footfall vibrations originating in adjacent corridors. The equipment room and the mechanical penthouse are common sources of vibration that can be propagated throughout a building by its structure. The size of the building grid, the selection of structural materials, and the need for other measures to stiffen the building may need review.

Vibration is characterized by frequency and displacement, which must both be considered. The vibration controls of general laboratory buildings may be insufficient for some instrumentation. If sensitive equipment will be used, it should be provided with special vibration-isolational mounts or tables. Poor planning regarding vibration control can be very costly. Slab-on-grade construction with well-compacted soil in intimate contact with the slab is usually a low-cost method for achieving particularly low vibration levels. Achieving desirably low vibration levels for upper-floor laboratory spaces usually requires a building structure that is substantially stiffer than a structure designed to meet average standards for strength (Ruys, 1990, pp. 387-388).

RESEARCH LABORATORY COST CONSIDERATIONS

Whether in academic institutions, corporations, or government, most scientists and laboratory administrators lack familiarity with the costs of building and/or renovating basic and laboratory-specific facilities.

Building costs are commonly divided into two components, construction costs and project costs. The former, the bricks-and-mortar costs, are discussed below. The latter, which encompass all other costs incurred by the client (e.g., nonbuilding construction costs, such as utility and construction permits; fees, such as site and materials testing fees; design professionals' fees; contingencies; and move-in activities) are detailed in the section "Project Cost Components" below in this chapter. Construction costs typically range from 65 percent to 80 percent of the total project costs.

Both construction and project costs for laboratory buildings are traditionally higher than those for other building types. Table 3.1 shows how the relative construction costs per square foot (adjusted for the Philadelphia area market in 1996) of several types of laboratory facilities compare with those for office facilities. Constructing or renovating laboratory facilities costs more because of their greater complexity, including, for example, requirements for specialized HVAC, mechanical, and electrical systems as discussed in the section "Building Services" above in this chapter.

Over the past 25 years, laboratory building construction costs have increased faster than the overall consumer price index owing to several factors: safety

TABLE 3.1 Comparison of Construction Costs for Various Types of Laboratory Facilities

	Relative Construction Cost[a]		
Facility Type	Low	Average	High
Office	0.5	1.0	2.0
Laboratory	1.3	2.0	2.8
Animal Research	1.5	2.3	2.5
Manufacturing	3.3	3.5	5.0
Biotechnology Production	5.0	5.8	7.5
Microelectronics Fabrication[b]	16.0	21.0	25.0

[a]All costs have been normalized to the average cost of office construction.

[b]The extremely high cost of constructing a microelectronics fabrication plant is due to the complexity of classified clean rooms, tight construction performance specifications, and usually very aggressive construction schedules.

SOURCE: Bender (1996).

considerations and regulatory requirements have increased the complexity of laboratory building design, users now demand better performance in laboratory buildings (particularly in mechanical, electrical, and information technology systems); and the number of manufacturers and suppliers has dramatically decreased for many laboratory building specialties, such as casework, cold rooms, chemical fume hoods, and sterilization equipment, thus reducing cost competition.

Budget Formulation

After a need is established for an improved, enlarged, or new laboratory facility, a budget can be established in a top-down or bottom-up process.

In the top-down approach, a board of trustees or executive authority considers the strategic benefit of meeting the need established, evaluates the overall financial impact and risk of committing resources to develop the facility, and, if the project is deemed desirable, allocates a fixed sum for it based on a thorough study of the need and alternate ways to meet it or simply on what resources are currently available. An approved project and budget are sent down the organizational structure to be executed to the extent possible by the facility manager in cooperation with the person(s) who initiated the original request. The design group, the client, and the users must determine a scope, quality, and schedule that fits the fixed budget.

In the bottom-up approach, the institution determines, in a predesign process, the scope, quality, and schedule of the project (see the "Predesign Phase" section in Chapter 2). The client then obtains estimates from competent cost estimators and construction experts who have extensive experience in estimating the costs of conceptualized laboratory projects. Gathering the necessary information is the first cost of the project.

The reality, however, is that often neither time nor funds are available for a thorough predesign process. In addition, even though a project's scope and justification may be adequate, resources currently available to the organization often are not. As a result, it may be necessary to reduce the scope of the project or to phase construction over a period of time. This is the first decision to be made in the project. Possible solutions include leaving some or all of the building a shell and, as more funds become available, constructing the laboratories floor by floor, if permitted; designing and constructing a smaller building and to plan for future addition(s) to the structure when funding becomes available; or phasing the construction floor by floor, or wing by wing.

Build Versus Renovate

Feasibility and Other Considerations

In addition to cost, the decision to build or renovate is based on feasibility and other considerations. Before making any firm decision, clients should arrange for a thorough study of the feasibility of renovation and reuse of an existing structure for laboratories. Many cities and communities have architectural review boards and historical-building commissions with the authority to deny amendments to zoning or occupancy permits for existing buildings for historical reasons, political and environmental considerations, structural capacity, or code changes.

Other factors influencing a decision to renovate or replace an existing building, include loss of use during renovation, time and phasing of construction, quality of renovated versus new space, and most important, anticipated performance of a renovated versus a new laboratory facility. Some of these issues are discussed in the "Predesign Phase" section of Chapter 2 and in the "Design Considerations" section above in this chapter.

Relative Building Cost

The construction costs for renovating technically intensive laboratories can equal those for erecting a new facility. Moreover, construction costs are only part of total project costs (see "Project Cost Components" below in this chapter). Total project costs for a renovation, which can be 1.5 to 2.0 times the construction cost, are often relatively greater than total project costs for entirely new construction, which can range from 1.2 to 1.5 times the "bricks-and-mortar" construction costs. Thus, overall project costs for major renovations often ex-

TABLE 3.2 An Example of Relative Costs for Renovation and New Construction of Laboratories

	Cost per Gross Square Foot[a] (in dollars)		
Level	Low	Average	High
Construction Cost			
Renovation			
Light[b]	78	84	90
Moderate[c]	120	135	150
Heavy[d]	180	195	210
New Construction	240	250	260
Total Project Cost			
Renovation			
Light[b]	117	147	180
Moderate[c]	180	236	300
Heavy[d]	270	341	420
New Construction	288	338	390

NOTE: These data are intended to show only relative costs for different types of construction, not current costs. Absolute costs for construction vary tremendously by geographical area and with time.

[a]Includes all floor areas included within the outside faces of the exterior walls.
[b]Primarily cosmetic, with no significant mechanical, electrical, or plumbing changes.
[c]Involves changes in occupancy, utilities, and ventilation.
[d]Completely replaces systems and fits out laboratories, as well as changes layout.

SOURCE: Muskat (1993).

ceed those for new construction projects. Table 3.2, which shows the relative costs of different types of laboratory renovation in the New York City region in 1993, gives an example.

Construction costs vary in different locations in the United States, ranging from highs in areas like New York City, Los Angeles, and San Francisco to lower costs in areas like Billings, Montana. Urban cores are more expensive to build in than are suburban areas. On the other hand, the costs are relatively invariant with institution type (academic, industrial, government).

Building Construction Cost Considerations

Quality, Scope, and Schedule Factors

When a fixed budget has been established for a project, there is generally a trade-off among the three factors of scope (size and complexity), quality (materials and construction detailing), and schedule (design, documentation, and construction activities). The construction costs of new construction and renovations, hence the total project costs, are consistently and directly affected by these three factors.

To maintain a fixed budget, increases in the quality of construction materials must be balanced by a reduction in the project's scope, or vice versa. If the schedule is to be accelerated, either the project's scope or its quality will have to be reduced to maintain the budget. A slow construction process, however, is not necessarily less expensive. Making slow or intermittent progress is less efficient and therefore more expensive than keeping to a normal construction schedule, such as that illustrated in Figure 2.1, Chapter 2.

For large laboratory construction projects, the total cost may be higher, but the cost per gross square foot may not be: large projects can achieve economies of scale in the purchase of materials, as well as labor efficiencies that cannot be achieved in small projects.

Complexity increases the cost of new construction, independent of the size of the project. Complexity factors range from site conditions to the number and quality of utilities installed in laboratory buildings. By definition, laboratory renovations are more complex than new construction projects, because existing conditions in laboratory buildings are varied and often hidden and may require unexpected adjustments or accommodation.

Life-Cycle Costing

Buildings are complex, long-term investments. Investment decisions made during the predesign, design/documentation, and construction phases of a project will affect building performance and functionality for the life of the facility. The life-cycle costing approach to the evaluation of building costs should be used as an overall philosophy for decisions concerning building performance.

The design group should provide not only initial cost estimates but also utility and maintenance cost estimates over the expected useful life of selected equipment, materials, and construction assemblies. This information enables informed choices to be made between lower initial cost or lower lifetime costs. Details of some of these choices are discussed in the section "Design Considerations" above in this chapter. A simple but complete model for life-cycle costing is best. The design group should list assumptions made and the effects of those assumptions. Each institution and controller's office has its own accounting model to verify these estimates. The client's facility operations groups should verify operating costs. When accurate cost data on operations are not available, good benchmark data should be sought from other buildings of comparable quality and complexity in the organization or in the local area.

Impact of Scientific Discipline and Special Laboratory Types

Although there are large and identifiable differences in the cost of constructing different types of chemical laboratories, it is difficult to generalize about the cost of one laboratory building versus another. Each laboratory has thousands of factors that must be taken into consideration by the client and the design group for quality, performance, longevity, and availability. When facilities are used as a benchmark, these differences should be taken into account.

Impact of Campus Utility Capacity and Distribution

Central utility plants (CUPs) often generate steam and chilled water that provide essential heating and cooling for laboratory buildings. CUPs can provide electrical power through cogeneration for large campuses. Savings can be significant if a plant is constructed with spare capacity in anticipation of future new or renovated laboratory buildings. If a CUP does not have adequate capacity in one or more key utilities, clients then face two options: add equipment in the CUP to expand capacity or place new equipment in the new or renovated building for either stand-alone operation or connection to the CUP distribution lines.

In making this decision, initial cost, life-cycle cost, and redundancy of capacity of utilities should all be considered. Adding to the CUP is often preferable because the redundancy of the facility both enables loads between campus buildings to be balanced and provides backup equipment if any one piece of equipment must be shut down for maintenance or replacement. For many research and development laboratory buildings, continuity of service is essential.

When enlarging a CUP is not feasible, an alternate strategy to achieve at least some redundancy is to link the chilled-water and steam-generating equipment in as many buildings as is practical. This strategy budgets for each new building, or renovation, funds for building equipment and for connection to the site loop. Long-term energy savings are not as easy to achieve as with a CUP, but savings are higher than in typical stand-alone installations.

Long-range utility expansion and replacement capital plans are a necessary part of the life-cycle approach. Accurate documents of utility usage are vital for planning. If documents are not available, funds must be budgeted to study all utilities before the scope is developed. Lack of proper definition on this subject can greatly affect the project cost.

Impact of Value-Adding Design Strategies

Flexibility and Adaptability

The very desirable characteristics of flexibility and adaptability in laboratory buildings can be achieved in many ways and at many scales. Options ranging from modular, generic laboratories to plug-in/plug-out or replacable modular casework can contribute to useful, long-term adaptability. The key issue, however, is that the utility distribution (ventilation, electrical/data, and plumbing systems) must have commensurate flexibility and adaptability. The value of providing additional capacity, adequate and accessible shutoff valves, capped "T" joints in utility mains for future connections, and accessible electrical and data panels cannot be overemphasized. Laboratory renovations occur more frequently in utility distribution than in any other feature. The ability to easily access the utility infrastructure for modifications and repairs often influences satisfaction with a laboratory.

Flexibility is the key to effective life-cycle costing. Built-in adaptability reduces renovation costs over the entire life of a laboratory. If an institution or organization has a record of undergoing frequent renovations and adaptations, initial costs to ensure flexibility can be quickly recouped. Flexibility also applies to programmatic flexibility: the ability to reallocate space. Because a small space is easier to reallocate than a large one, the inclusion of a few small modular laboratories per floor can be cost-effective.

Sustainability

Sustainability or green design is an international trend in the chemical industry and in both architectural and engineering disciplines. Hundreds of options in laboratory design improve and conserve the inside and outside environments. Selection of energy-control systems, materials and methods of construction, and pollution-control mechanisms during construction and their proper use during occupancy are critical aspects of sustainable design. The cost feasibility of sustainability should be evaluated in the context of life-cycle costing, whereby the (sometimes) increased initial cost may be reclaimed by long-term maintenance and energy savings, or reduction of regulatory burdens.

Sustainability is much more than energy efficiency. Other aspects include the use of water, the impact on the environment when the building materials are produced, the air quality of the building, and so on. For example, the landscaping can be done with water-efficient, low-maintenance plantings that limit the use of water and pesticides, and the pollution from mowing. Water demands within a laboratory can be reduced through the use of central vacuum systems that replace the need for water aspirators if used. The reduced load on the laboratory waste system can reduce the size of the waste system components.

Although prevalent in small-scale applications, sustainability on a large scale is a particular challenge for laboratory buildings. At present, little information is available about construction premiums and operating savings in the few large-scale sustainable laboratory buildings that have been designed. It may take another decade to recognize the most cost-effective strategies for achieving sustainable laboratories. However, one common practice applicable to laboratory facilities is the installation of heat-recovery systems on the fume hood exhaust air systems. Closed-loop glycol systems, although less efficient than heat-wheel systems, eliminate the possibility of supply air contamination.

Low Operating and Maintenance Costs

Many occupants of university and government laboratories are not familiar with the operating and maintenance (O&M) costs of their laboratory procedures and normal operating modes. Often individual buildings on large campuses have no meters for basic utilities; there is no accountability for O&M cost control by decision makers in departments or schools that use those buildings. Some corporate laboratories, perhaps because of their for-profit orientation, provide information and financial incentives to their building occupants to save on O&M costs. Management strategies involving discounted charge-backs for utilities or for the use and maintenance of space are rarely if ever applied to academic buildings.

Investments in equipment and practices that reduce operating costs are necessary for new laboratory buildings. Most laboratories are energy intensive in part due to their nonrecirculating HVAC systems. Additional attention to energy efficiency is therefore warranted. Operational cost projections and energy audits of the HVAC system design are a good investment. Initial costs should be compared with life-cycle costs. For example, an 1,800-ton chiller that uses 0.451 W/ton costs $50,000 less per year to operate than one that uses 0.52 W/ton. Clearly the former will recover its greater initial capital cost—about $45,000—in less than a year.

Energy-Efficient Design

National guidelines and state building codes require energy-efficient design for general building lighting. However, there are no generally accepted national guidelines for heavy energy consumers such as research and development laboratory buildings.

Costs and Cost Control During Design and Construction

Predesign Phase Activities

Prior to the design/documentation phase, many activities may take place to justify a project, formulate the budget, or reduce the risk of making a poor facility investment. As discussed in the "Predesign Phase" section of Chapter 2, each of these activities deals with project uncertainties such as scope and function, quality and performance, and the time frame from site acquisition to construction phasing and move-in. Each of these factors has an impact on the budget. The magnitude of the budget and the effect of these factors on the desired building or renovation should be explored before a formal design process is undertaken if the budget is not predetermined. A preliminary budget should be estimated before preliminary design commences and then should undergo final revision when a schematic design is completed. If the budget is preset, all design work must take this limit into consideration. In addition, given the considerable uncertainty in the cost of a construction project, the reliability of the materials, the schedule, and other aspects of the process, assorted contingencies (see "Contingencies" below in this chapter) should be established early in the process. As the project progresses, contingencies can be recovered or the funds shifted to other uses.

Generally, there are costs associated with all predesign activities either in time for the in-house staff or in fees for design professionals and estimating services. Although predesign costs are frequently omitted from building or renovation budgets, these costs are typically offset by the lack of schedule delays, improved definition of the project's requirements, and attainment of a superior building that maximizes users' desires and minimizes costly changes in design. Predesign costs were estimated by the experts consulted by the committee to be typically less than 2 percent of the project budget.

Design and Documentation Phase Activities

The three main phases of design/documentation are discussed in Chapter 2. They are schematic design, design development, and construction documentation. In each phase, important choices arise concerning size, quality, complexity of materials, and methods that affect the cost of the project. For each phase there are design milestones at which the design group asks the client team or other client representatives to make critical decisions. These decisions will be based on the information provided by the design group, by the client's consultants, and by the client's previous experience in managing laboratory buildings. Effective cost control is achieved by considering the project goals and performance requirements in all design decisions and by recognizing that many small, seemingly insignificant, decisions by the user, owner, or design team can add a larger amount to the project cost than one would initially expect—and then acting accordingly.

Schematic Design. If a predesign phase is not conducted, the activities normally completed during that phase, such as identification of project goals, scope definition, and site selection, will need to be carried out during the schematic design phase. Following the completion of these preliminary activities, the design group documents the site through architectural and engineering concepts in drawings and preliminary specifications. Engineers and architects provide written descriptions of recommended building and utilities systems, materials, and methods of construction. The cost estimator or the client's construction manager, or both, use this information to develop a preliminary construction cost. If two estimates are developed, appropriate members of the client group plus responsible members of the design group meet with both estimators to understand the estimators' and design professionals' assumptions, to check that the estimates are comprehensive and accurate, and to reconcile any major differences between the estimates.

The client and the design groups review the schematic estimate(s) and either reconcile the cost estimates or proceed to the next stage of design development. If there is agreement in the reconciled estimate, and confidence that the design meets the client's goals and budget, the client may decide to reduce the design contingency. Cost control is achieved in this phase through design selection. Before this phase can be concluded the client will need to develop the overall budget for the project including construction and project costs. If the budget is externally mandated and projected estimates are higher, value engineering should begin at this point.

Design Development. During design development, the design group completes documentation of the design concept. Descriptions of design work done during this phase are detailed in the section "Design and Documentation" in Chapter 2. The cost estimator and the client's construction manager use this information to estimate construction cost. The cost estimates are evaluated and reconciled. The client group, the client team, and the representatives of the facilities and operations departments then refine the total project cost, the construction cost, and the other project cost components. For this step, the client may also request the assistance of the design group, which may be able to provide examples from previously completed projects.

If the project or reconciled construction estimates are over budget, the design group begins a formal process of generating options to reduce costs to present to the client for a decision(s). This process is commonly called "value engineering" by construction managers. Careful evaluation of alternatives should be based on the goals and performance objectives that were originally established. Operating and life-cycle costs should not be ignored in efforts to reduce initial costs, and the essential quality and scope (program effectiveness) of the project should not be sacrificed. This process calls for careful investigation and wisdom.

Construction Documents. In the construction documents phase, the design group develops and documents construction details with all engineering systems integrated and coordinated with the plans, sections and elevation drawings, and specifications. In addition to completing comprehensive and coordinated construction documents, the design group also has cost control and constructability as main objectives during this phase. The design group translates the design concept into the language and metrics of construction. Construction contractors and subcontractors, and materials and equipment vendors, use construction documents for their bids. When a contractor and its subcontractors are awarded the construction contract, the documents instruct the laborers and tradespeople.

So that all these functions can be performed successfully, construction documents must be complete, thorough, coordinated, and accurate. The quality of these documents directly affects the number and cost of change orders submitted during construction. Change orders add cost to a base construction contract. In addition, if "low-bid" awards are mandated by the funding authority, only items detailed in these documents will be built, and they will be constructed only as detailed. Money spent to verify their completeness and accuracy is well repaid through reduction of change orders. Means of verifying the accuracy and completeness of documents are discussed in Chapter 2.

To keep the design within budget, design architects and engineers request materials and equipment costs from vendors and subcontractors. They continually evaluate cost-effective systems and methods of construction that meet the client's quality and performance requirements.

To confirm that the project remains within the construction budget, detailed estimates or updates of estimates are recommended during the construction document phase. The estimates completed during this phase are typically based on documents that are 50 to 75 percent complete. If there is reason to believe that there is "creep" in the scope of the project during this phase, the client may require additional updated estimates based on construction documents that are 75 to 90 percent complete. Following the completion of each of these estimates, the client may require the design group to conduct formal cost reduction exercises, as mentioned above. In addition, the design group may include "add and deduct alternatives" within the construction documents to respond to an uncertain bidding climate. "Add" alternatives provide additional or improved quality and additional materials and equipment to the project; "deduct" alternatives reduce quality and scope. If the selected contractor's price comes in lower than the budget, the client can decide to select one or more of the add alternatives that meets the budget. Conversely, should the bids exceed the budget, the project scope or quality, or both, may require reduction.

The client continues to develop and refine the list of and cost for the nonconstruction components (itemized in "Project Cost Components" below in this chapter) that, along with the basic construction cost, constitute the project cost.

Construction Phase Activities

Bid and Negotiation Activities. This phase establishes the contract price for construction, the details of which are discussed in the "Construction Phase" section of Chapter 2. Unless previously established, a construction contingency must be determined that represents client funds available above and beyond the accepted construction price, which is based on a bid, or a guaranteed maximum

BOX 3.15 Construction Contingency Considerations

- Contract method
- Client's (or design group members') previous experience with a successful contractor and subcontractors
- Condition of the construction market
- Complexity and timing of the project

price. Since the construction documents are complete at this time, the design phase contingency is no longer required. Based on the factors given in Box 3.15, the client, with assistance from the design group, will set the construction contingency and other project-cost-related contingencies.

When the price is determined, the schedule agreed to, and the client's construction contract signed, the bid and negotiation stage is complete. The client releases the contractor to commence construction.

Construction Administration Activities. Construction administration refers to the efforts of the design group and client group during construction and before occupancy. Cost control in this phase focuses on reducing the number of change orders and achieving quality construction so work does not have to be torn out and reconstructed.

Construction Review. Ideally the client engages an experienced construction inspector to continuously review the construction activities during the entire construction period. During the construction review, the client's inspector inspects building materials and equipment brought to the site and validates labor slips for all construction workers. This individual works diligently to reduce change orders and substitution of inferior materials in the construction, thereby controlling costs.

The architects and engineers also employ individuals to review the progress of the construction activities. These construction administrators check shop drawings from vendors and subcontractors, issue responses to requests for information from contractors, recommend acceptance or rejection of change orders to the client, and approve applications for payment to the general or primary contractor. One of the construction administrator's responsibilities is to help control change orders and control costs.

Construction Supervision. Construction supervisors, employed by the general contractor, manage the delivery of materials to the site and supervise the overall work force. The supervisor issues requests for information to the design group, manages the distribution of shop drawings, and provides estimates for change orders. Because this individual typically plays a vital role in the success of a laboratory construction or renovation project, he or she should be carefully selected by the client team and design group if it is possible to do so.

Change Orders. "Change order" is a term that refers to both the documentation and the process for approval of modifications to the contract documents during construction. Change orders can be initiated by all three parties to the design and construction contracts—the client, the design architect/engineer, and the contractor or subcontractors. Change orders are used to correct, modify, and add essential materials or details to accomplish the intent of the contract documents. They are a mechanism for correcting errors arising from lack of coordination between subcontractors as well as design errors or omissions; they are also generated when a client changes the scope of a project or modifies previously approved components. In some projects, if the construction documents have not been completed or coordinated prior to the initiation of the construction phase, the architects and engineers continue to complete the construction documents during the construction phase, often creating additional change orders. It is often better to delay the bidding and negotiation period until the client team and the design group are confident that the construction documents are complete and coordinated.

Change orders are initially approved by the design group and finally approved by the client. The architect/engineer submits to the client recommendations for the changes requested by the client or required by code or for some other reason. The contractor provides the price of the materials and labor to complete the modification. The contractor may also provide alternatives and recommendations for accomplishing the desired results.

The cost of change orders is offset by the client's construction contingency. Change orders not initiated by the client should not exceed 5 percent of the construction cost for a typical laboratory project and should ideally fall below 3 percent. The best way to avoid those change orders not initiated by the client is to verify that the construction documents have been competed, are accurate, and are coordinated. Many architects and engineers perform substantial quality reviews and coordination of documents to reduce the potential for change orders.

The design group and, if one is engaged, the construction manager should carefully scrutinize change orders initiated by the contractor or subcontractors, as should the client project manager. Cost control is achieved by controlling contractor-generated costs for all change orders. Public agencies and institutions may be vulnerable to excessive requests for change orders because of low-bid acceptance practices. Government and public construction projects typically experience far higher levels of change orders than do projects that are negotiated with prequalified contractors or those that do not require taking the lowest bid.

Project Cost Components

Nonbuilding Construction Costs

Prior to actual construction, there are many other activities for which the client may have to budget depending on the conditions of the site selected for the laboratory building,

Land. The site for the proposed building or campus, if not already owned, must be purchased. Owners should consider the impact of future expansion of the laboratory facility on the site. If adjacent parcels are available, purchase of land for a temporary buffer and long-term site for expansion may make a good investment. Brown-field sites have existing buildings and usually some site utilities. Green-field sites are free of buildings and often free of roads and all utilities. Both categories of sites need careful evaluation regarding the cost to bring construction materials to the site or to move utilities and roads and to deal with other encumbrances such as drainage.

Sites for new construction and even major building renovations require site area for construction staging, which includes construction trailers, parking for workers, and secure storage of building materials and heavy equipment.

Demolition. Some demolition may be required if the site has existing structures that obstruct the footprint or the immediate construction zone of the proposed building. Demolition is normally required in renovations. The extent of demolition ranges from select limited demolition to total interior demolition of the spaces or building to be renovated and everything in between. Selected limited demolition may remove only certain laboratory building components, such as mechanical systems or laboratory casework. Gut demolition removes everything down to the basic building shell. Often windows and roofing are also removed and replaced.

Because laboratories and laboratory buildings contain hazardous materials, preliminary investigations and an industrial hygiene survey should be undertaken well before completion of the design documents for the renovation. If hazardous materials are present, in ducts, pipes, chemical hoods, and so on, they must be properly removed and the building remediated to safe condition prior to demolition. This is an extra cost inherent in laboratory building renovation.

When existing structures near or in the immediate construction zone will continue to be occupied during the construction of a laboratory, the foundations, exterior walls, windows facing the construction side, and roof must all be protected—a responsibility of and cost to the client whether or not the client owns the abutting building.

Special Foundations. If a laboratory building is constructed as an addition to or very close to an existing building, underpinning of the existing building's foundations may be required. Underpinning is done when excavation for the new building's foundation extends beneath the existing building's footings or for some other reason that may cause temporary or permanent unstable conditions. Underpinning involves installing structural elements beneath or beside existing foundations to support the existing building. For similar reasons, sheeting may be installed to stabilize and support the earth around the foundation of an existing building next to an excavation. These and other special foundations represent costs borne by the laboratory building owner.

Site subsurface investigations and geotechnical surveys are normally conducted very early in the design process, if they have not already been done in a feasibility study or during site selection. Laboratory buildings constructed in regions of documented seismic activity also often have special foundations, structural design, and construction costs associated with them. Laboratories with sensitive analytic equipment may also require special foundations, such as pilings or piers to bedrock, in order to isolate the building from local vibration.

Site Utilities. Subsurface site investigations on many developed sites reveal existing campus utility and city service lines. If it is not feasible to relocate these obstructions to construction, then the utilities must be supported and protected during excavation and construction. Temporary shutdown of certain utilities may be necessary during installation of these protective measures. If not considered early during design, this step costs both money and time in a construction schedule. New utilities may have to be brought through or to the site, such as fiber-optic cable. They, too, have to be planned and budgeted.

Site Work and Landscaping. An integral part of design is site and landscape design. Landscaping is a small part of the entire construction budget but has a significant and immediate impact on the entire image of the laboratory project, as well as on the environment. Good landscape design and siting can influence the community's acceptance of a laboratory facility. Well-designed sites provide laboratory staff with places for psychological respite and physical recreation. See the section "Sociology" in Chapter 1 for more information.

Permits. Permits are usually a direct expense to the client, although the contractor may pull the permits and work with the building department of the municipal government. In some jurisdictions permits are required for services such as water, natural gas, and sewer connections, for exhaust discharge, and for other activities with environmental impacts. These permits are required above and beyond the ordinary building permit. Central utility plants must comply with particular environmental regulations, such as for sulphur dioxide and nitrous oxide emissions.

Owner Supervision and Institutional Surcharges. Many institutions and corporations have qualified and experienced in-house staff members who manage program, design, and construction processes, as well as maintenance and operations. The work that these staff members perform may be charged directly to the project on a fixed fee or hourly basis. Some organizations perform actual construction management, holding contracts from the general contractor and subcontractors and scheduling and coordinating construction activities. This is a major responsibility and requires a major commitment of personnel by the organization. The project budget should include the necessary salaries for the full-time staff.

Mock-up Construction. A mock-up of a typical laboratory space and even of adjacent areas, such as service corridors or laboratory support cores, is an extremely useful preconstruction tool. Laboratory mock-ups can be constructed as early as the design development phase or, more commonly, during the construction document phase of the design process. Mock-ups can be assembled with the actual full-size casework in the design configuration and finish materials with fittings, fixtures, and even pipes, conduits, and ducts. These are installed within a temporary shell constructed of lightweight enclosure materials, such as painted homosote or plywood. The mock-up can also be assembled in the actual building shell. Major architectural features in full scale, such as windows, doorways, lighting fixtures and ceiling heights, should be simulated to provide as realistic a model as possible.

The laboratory mock-up has two major functions. One is to allow early, and the most effective, feedback on the laboratory design, finishes, and material selections from future building occupants, health and safety professionals, and maintenance personnel. As many participants as possible should be encouraged to walk through the mock-up and comment on it. The comments should be used to improve the laboratory design. Mock-ups can be used for training operations and maintenance staff. Some mock-up components can be stored and reinstalled in the actual building.

The second function of a laboratory mock-up is to give a preview to construction contractors who will bid on or negotiate the construction cost. Inspection of the major components, materials, and quality of the construction offers important insight regarding the intent of the design and it supplements the design documents. Some clients have achieved measurable savings in bids offered by contractors when a mock-up was made available for investigation.

If the laboratory mock-up is delayed until the construction contract is let, very little change can be achieved economically in the original design, because the price is already fixed.

Fees. In addition to the actual cost of construction, clients must budget for service fees for design, construction, EH&S, and legal and financial professions, as well as for other nonconstruction costs. Basic architectural design fees do not normally include any special consultants or any additional services, unless their inclusion is specifically negotiated with the design team. Basic fees also do not include reimbursable expenses, which typically include costs for travel, telecommunications, mail and delivery, and document reproduction, not only for the prime architect and engineer but also for their consultants.

Services. Architectural and engineering design consists of basic services for the design of a building or renovation, such as architectural, structural, mechanical, electrical, and fire protection engineering services. The obligations of designers and owners and deliverables from designers are outlined and described in design service contracts such as the American Institute of Architects' B141 Standard Form of Agreement between Owner and Architect. Standard fees are usually expressed as a percentage of the construction costs. While the Brooks Act[4] limits such fees to 6 percent for federal projects, fees for new laboratory construction are more commonly in the range of 7 to 9 percent for projects with construction costs of $10 million to $50 million (more for smaller projects, less for larger projects). For renovations the fees are often 25 to 35 percent higher than those for new construction.

Additional design-related services include all predesign activities, such as planning and programming, and design studies such as energy audits, architectural models, and mock-up construction documents. Fees are associated with each of these services. Although basic design fees for federal projects are limited by the Brooks Act, total design-related services for such projects are more commonly 10 to 14 percent of the construction costs.

Consultants are hired to perform specific design tasks and to offer information for specific requirements of the laboratory design. Either the client or prime architect/engineering firm may enter into a contract with consultants. Consultants who often assist the prime design team for the laboratory building or renovation include a laboratory planner, laboratory safety professional, environmental engineer, code consultant, geotechnical engineer, vibration-control structural engineer, acoustical engineer, lighting engineer, construction cost estimator, information and audiovisual technology specialist, interior designer, and landscape architect. Clients may hire an economist to perform a market analysis or economic feasibility study. Because legal issues are always a consideration for owners during design and construction, legal assistance is highly recommended for contract negotiation.

Construction managers are often hired by clients to assist with cost estimating, scheduling, and improving the efficiency of construction of the design dur-

[4]P.L. 92-582, the Brooks Act of 1972 to amend the Federal Property and Administrative Service Act of 1949.

ing the design process. During the construction phase, construction managers may continue to represent clients by assuming major managerial responsibilities for scheduling and cost control. Construction management fees are a major expense in laboratory projects.

Construction supervisors hired by the clients are independent of the contractor. They perform inspection services and directly represent the client at the construction site. In complex construction, such as laboratory buildings or in difficult site conditions, the engagement of dedicated supervisors who are experienced and qualified is recommended.

Site and Materials Testing. In construction projects, site and materials testing fees are normal expenses of a client. Concrete, steel welds, soil and subsurface conditions, and curtain wall assemblies (preformed outer walls that are attached to the basic building frame) are typically tested and certified to meet design specifications. Other testing may be performed on other building materials such as driveway paving, brick, or stone.

Zoning Amendments, Environmental Impact Studies, and Public Hearings. Zoning amendments and hearings are a source of additional expense for the services of design professionals and legal counsel to prepare documents and present the owners' reasons for amendment to government agencies and, if required, to the public. Similar efforts and considerable expertise are required from design professionals, legal counsel, and a wide array of engineers, biologists, archeologists, and other specialists to perform environmental impact assessments or environmental impact studies. Public hearings are often required for approval of environmental impact assessments.

Surveys. A wide variety of surveys may be required to obtain information required for the design of the laboratory building and site. Surveys include land and site utilities, soils, traffic, vibration, and wind conditions. Equipment surveys are highly recommended to inventory existing scientific equipment that will be moved into and reinstalled in the new or renovated laboratories. Equipment surveys can include a listing of new movable, as well as fixed equipment, that will be purchased by the client and installed. The laboratory planner consultant can perform this survey if in-house staff cannot.

An industrial hygiene survey is recommended for a major renovation of laboratory buildings and when the presence of hazardous materials is suspected. Owners bear the cost of and responsibility for most surveys, but the architect/engineer can manage the process if this service is included in the contract.

Furnishings, Fixtures, and Equipment. Furnishings, fixtures, and equipment, or FF&E as this cost item is called, can be a very large component of the project cost. Furnishings, fixtures, and equipment are not included in the basic design or typical construction contract. The only items in this category that are covered in both laboratory design fees and construction costs are "fixed" equipment, such as chemical fume hoods or glass washers and autoclaves, fixtures, and "built-in" furnishings, such as fixed work counters or reception desks.

Movable FF&E items must be budgeted separately. Movable furnishings in a laboratory building include laboratory chairs and tables, office and guest chairs, conference tables, desks, file cabinets, bookcases, and other standard open-office partitions and furniture. Installation of all other furnishings and fixtures should be an item in the budget.

Movable equipment includes scientific equipment that is not permanently installed, such as nuclear magnetic resonance and mass spectrometers, centrifuges, refrigerators, microscope tables, computers, and the like. Installation and recalibration of equipment are discussed in the section "Installation and Calibration of Scientific Equipment," below. Fixtures in a laboratory building may include window coverings and treatment, decorative plants, and artwork.

FF&E costs for new laboratory buildings and renovations can range from 10 to 30 percent of the construction budget. Clients need to manage the FF&E selection and budgeting processes carefully or hire consultants such as laboratory planners and interior designers to assist them with this activity.

Information Technology. Telecommunications, video, security, and data systems installation are an increasingly critical part of laboratory buildings. Many systems and levels of technological sophistication are available according to the immediate and projected future needs of the building occupants and owners. In laboratory buildings, budgets for information technology normally range from 5 to 15 percent of the construction cost. Again, this is a big ticket and complex item, as is FF&E, and requires careful planning with the assistance of in-house information technology specialists or consultants. There are options for distribution of communications cables, such as cable trays and conduit. Basic design services and typical construction contracts do not include pulling wires or making final connections to terminal outlets and devices.

Finance Costs and Bonding. Interim financing may also be required for a laboratory renovation or construction project. Bonding protects the client against some of the financial difficulties and potentially catastrophic failures or delays in the construction process. Bonds that are recommended under normal construction conditions are bid, performance, payment, and price-escalation bonds.

Insurance Costs. Insurance is important to protect clients from a wide range of liabilities, such as public liability, vehicle liability, property damage and fire coverage, vandalism, workmen's compensation, and employees' liability. Other insurance may be needed according to the specific conditions of the site, existing building(s) in the case of renovations, and the construction contract. Clients should consult with expert insurance agencies to provide the appropriate scope and level of coverage required for each project.

Contingencies

Contingencies—funds reserved for unanticipated events—are diverse and cover many aspects of the design and construction process. Owners should structure contingencies sensibly to cover the risk of unknowns and factors that emerge, or that become priorities, during the 2- to 5-year design and construction process.

Design Contingency. The most commonly used contingency is the design contingency. During the design process, the estimated construction cost is increased by a carefully determined percentage to account for unknown design components and construction factors, not changes in the scope of the project. (See the section "Program Contingency," below, for information on scope modifications.) As the design is developed and comes to closure during later stages of construction documents, the design contingency can diminish. According to the complexity of the new laboratory project or renovation, the design contingency can be as much as 20 percent in the schematic design stage. It drops to 5 to 10 percent at the end of the construction documents phase.

Construction Contingency. After the bidding or price negotiation process is completed, the client's construction contingency should be reconfirmed. This contingency is spent as construction proceeds and modifications to the contract documents (change orders) are requested by the client. At the end of construction the client can apply remaining construction contingency funds to other project cost items or to the organization's general funds.

The general contractor will maintain and control his or her own construction contingency during the course of the project to cover unforeseen construction factors. Because laboratory buildings are complex, it is prudent to provide adequate contingencies.

Program Contingency. The program contingency, the owner's responsibility, budgets for possible changes in the scope, quantity, or quality of the project. If the nature or size of any of the building components is increased or decreased, the program contingency is used to finance the change and allow continuation of the construction.

Consultants Contingency. The consultants contingency is a small fund set aside during the design and construction phases to pay for additional services that are needed or other specialty consultants required to resolve issues or problems that were unforeseen.

Equipment Contingency. As discussed in "Furnishings, Fixtures, and Equipment" above, an FF&E budget is difficult to develop and estimate accurately. An equipment contingency is used to fund any shortfall in the estimate or for modifications in quantities or quality of items in the FF&E schedule.

Financing Contingency. A financing contingency offers the owner a budgetary cushion for unforeseen circumstances that might affect the funding available for the project. The amount or proportion required for this contingency is based on the amount and nature of risk.

Costs of Move-in Activities

The moving costs associated with a laboratory construction or renovation project can involve more than the expense of transferring the contents of one building into another. Move coordination—identifying what moves, what stays, and what gets discarded—is a formidable task. A move to a new or renovated laboratory is the ideal time to dispose of old chemicals and establish a department-wide computerized chemical inventory system. The one-time costs associated with these activities need to be budgeted. Moving costs may include those for use of temporary facilities, building commissioning, installation and calibration of scientific equipment, and hazardous materials assessment, transportation, and disposal.

Use of Temporary Facilities. Temporary facilities may have to be leased to accommodate phasing of renovations or even with new construction if the schedule for completion does not coincide with the demand for functional laboratory space. Short-term laboratory rentals are generally expensive and hard to find. Office facility rentals are easier to negotiate.

Although it would be expensive, manufactured mobile laboratory units can be purchased, transported to an open site, and installed to site utilities. Mobile laboratory units are approximately the same size as mobile homes and construction trailers. Units can be joined to form doublewide units. As a practical matter on a campus or site, only a limited number of scientists can be accommodated in mobile laboratories. Alternately, the feasibility of dispersing laboratory occupants temporarily into other operating laboratories within the organization can be explored if necessary.

Commissioning. The objective of commissioning is to have the building systems perform as designed and as specified. This process is described in the section "Postconstruction Phase" in Chapter 2. Building commissioning has received a great deal of attention in the past few years from building owners because new building systems have routinely failed to perform acceptably. Problems with heating, ventilation, and air conditioning systems are particularly frequent upon start-up. Commissioning should be done by an independent agent, not the design engineer, construction manager, or contractor, in order to obtain an objective, unbiased evaluation of building systems. Many institutions strongly believe that commissioning should be part of the design engineers' or general contractors' basic services. This arrangement is the ideal, but complex buildings such as laboratories really deserve a second, objective inspection. Fees for commissioning services range up to 1.5 percent of the construction cost.

Installation and Calibration of Scientific Equipment. The budget for a laboratory construction or renovation project should include realistic and adequate costs to provide for installation and calibration of all major scientific equipment moved into any temporary facilities and finally into the completed new building or renovation. Surveys of scientific equipment give clients an indicator of the scope of the installation effort. Some scientific equipment can be installed either by the construction contractor or by the vendor or service agency for the equipment. The installer should be selected according to the value or sensitivity of the equipment, or both, not just according to lowest cost. If some of the instruments are installed by the contractor, most will still require calibration.

RECOMMENDATIONS

To address the technical issues in a laboratory design, construction, or renovation project, the committee recommends the following actions:

1. **Appoint an environmental health and safety technical advisor.** An experienced EH&S professional is needed to advise the client team in all phases of a laboratory construction or renovation project.
2. **Establish communications with regulatory authorities.** Early in the project the institution should develop a working relationship with regulatory authorities whose approvals are necessary for various aspects of the project.
3. **Consider design alternatives.** Explore alternative solutions for fulfilling needs.
4. **Complete predesign before committing to a budget.** If possible, defer setting the budget total until completion of the schematic design phase, when the scope, concept, and special conditions of the project are determined.
5. **Obtain cost estimates.** Construction cost estimates should be obtained from at least two separate, experienced sources, and the estimates should be reconciled at the end of each phase. Develop a list of project cost items as early as possible. Carefully review all bids, and compare them to design-phase estimates.
6. **Set adequate contingencies.** Even with the best planning, some changes will be necessary.

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Appendixes

Appendix A

Biographical Sketches of Committee Members

John I. Brauman, committee chair, is the J.G. Jackson and C.J. Wood Professor of Chemistry at Stanford University. Dr. Brauman's research centers on structure and reactivity of organic and organometallic compounds in solution and in the gas phase. A physical organic chemist, he received his B.S. in 1959 from the Massachusetts Institute of Technology and his Ph.D. in chemistry from the University of California at Berkeley in 1963. Dr. Brauman is a recipient of numerous awards including the American Chemical Society's Award in Pure Chemistry, the Harrison Howe Award, and the James Flack Norris Award in Physical Organic Chemistry. He is a fellow of the American Association for the Advancement of Science and a member of the National Academy of Sciences. He is deputy editor for physical sciences for *Science* magazine and has served on several National Research Council panels and committees, including the Committee on Risk Assessment of Hazardous Air Pollutants.

John L. Anderson is the dean of engineering and a professor of chemical engineering at Carnegie Mellon University. His research interests are in colloid science, membrane transport and separations, fluid dynamics, and bioengineering. He received a bachelor's degree in chemical engineering in 1967 at the University of Delaware and a Ph.D. at the University of Illinois (Urbana). He is a member of the National Academy of Engineering and is co-chair of the National Research Council's Board on Chemical Sciences and Technology.

W. Emmett Barkley is the director of laboratory safety at the Howard Hughes Medical Institute (HHMI). Dr. Barkley directed the National Cancer Institute's office of research safety and the divisions of safety and engineering services at the National Institutes of Health before joining HHMI in 1989. He received his B.S. in civil engineering from the University of Virginia in 1961 and his M.S. and Ph.D. in environmental health from the University of Minnesota in 1966 and 1972, respectively. Dr. Barkley has received of numerous awards, including the Distinguished Service Medal of the U.S. Public Health Service. He served on the National Research Council's Committee on Prudent Practices for Handling, Storage, and Disposal of Chemicals in the Laboratory and was the chair of the Committee on Safety and Health in Research Animal Facilities.

Janet S. Baum is an architect and the founder of Health Education + Research Associates, Inc. (HERA). Ms. Baum specializes in the programming, planning, and design of technical facilities. Her experience focuses on state-of-the-art institutional and corporate research facilities in the traditional scientific disciplines, as well as in biotechnology and materials science. Before forming HERA, Ms. Baum was director of Science and Technology Facility Design at Hellmuth, Obata + Kassabaum-St. Louis. During the past 32 years she has programmed and planned the renovation or construction of numerous chemistry, biochemistry, and medical facilities and has written several books on laboratory design principles. She received a B.S. from Washington University in 1966 and a master's of architecture from Harvard University in 1970.

Robert H. Becker is the research planning manager in Workplace Strategies and Operations at Monsanto Company, specializing in Agricultural Research Growth Facilities. He has worked on projects for research facilities/workplace planning for biotechnological, pharmaceutical, and agricultural facilities at Monsanto. He is a civil structural engineer with extensive experience in operating and designing, developing, and building research facilities. He received his B.S. in civil engineering from the University of Missouri in 1969 and his M.S. in engineering management from the University of Missouri at Rolla in 1971. He is a registered Professional Engineer and a certified facility manager with the International Facility Management Association.

Peter J. Bruns is a professor of genetics at Cornell University. He is a biologist who conducts research in molecular and developmental genetics. He received his A.B. from Syracuse University in 1963 and his Ph.D. in cell biology from the University of Illinois in 1969. He served as associate director of the Biotechnology Program at Cornell University, overseeing the design and construction of the biotechnology building. He has served on the editorial board of *Current Genetics* and of the *European Journal of Protistology* and as an associate editor of the *Journal of Experimental Zoology*.

Carol Creutz, chair of the Department of Chemistry at Brookhaven National Laboratory, is an inorganic chemist whose research interests include electron, atom, and proton transfer reactions; photochemistry of transition metal complexes; small molecule coordination; and catalytic chemistry. She received her B.S. from the University of California at Los Angeles in 1966 and her Ph.D. in chemistry from Stanford University in 1970. She has served on the *Inorganic Chemistry* editorial board. She was a member of the National Research Council's Committee on Prudent Practices for the Handling, Storage, and Disposal of Chemicals in the Laboratory.

Daniel L. Hightower, director of Facilities Management at the University of Kansas, is an architectural engineer who has had extensive experience in laboratory design and planning. In his previous position as associate director for management controls and policy in the Division of Engineering Services at the National Institutes of Health (NIH) he helped write *NIH Design Policy and Guidelines.* He is a member of the American Institute of Architects' steering committees for "Guidelines for Construction and Equipment of Hospitals and Medical Facilities" and the new "Guidelines for Biomedical Research Laboratories." He received his B.S. in building design and construction from Pittsburgh State University in 1971 and his M.S. in architectural engineering from the University of Kansas in 1974.

David R. Parker is the administrator of the Hazardous Materials Division of the Santa Clara Fire Department. He consults on issues of hazardous materials storage, handling, and use; reviews building plans for facilities using hazardous materials; and inspects work done on such facilities. In addition, he has worked as a chemist in the chemical industry, at Clorox Corp. He received his B.S. and Ph.D. degrees in chemistry from the University of California at Davis in 1968 and 1976, respectively.

Frank J. Popper is a professor of urban studies at Rutgers University. He is an expert on locally unwanted land use. He has written extensively on the topic of land use, serves on the editorial boards of several land-planning journals, and consults on land use for various organizations. He received his B.A. in psychology from Haverford College in 1965 and his M.P.A. in public administration and Ph.D. in political science from Harvard University in 1968 and 1972, respectively. He has received the Rutgers University Presidential Award for Distinguished Public Service and the American Geographical Society's Paul Vouras Medal for regional geography.

Charles A. Potter is a research scientist with Hercules, Inc. He is a general analytical chemist whose current research is focused in the area of thermal analysis. He has been involved in coordinating the renovation of a large laboratory building in a research complex that contains facilities ranging from research laboratories to a pilot plant. He received a B.A. in chemistry from the University of Connecticut in 1975, a Ph.D. in analytical chemistry from the University of Georgia in 1979, and an M.B.A. in 1985 from the University of Delaware.

Michael Reagan is an architect and vice president of Ellenzweig Associates, specializing in the programming, design, and construction administration of scientific research and teaching facilities. His major projects over 20 years include science research and teaching facilities for major universities, colleges, and private industry. He serves as a member of the Project Kaleidoscope steering committee for facilities. He received a bachelor of environmental design from Miami University and a masters of architecture from the University of Michigan, and he has completed advanced studies at the Architectural Association School of Architecture in London.

Paul R. Resnick, retired, was a DuPont fellow employed by DuPont Fluoroproducts. He is an organic chemist whose research focused on fluorine chemistry. He has been involved both in laboratory renovations and in building a new structure for chemical research. Dr. Resnick received his B.A. from Swarthmore College in 1955 and his Ph.D. in chemistry from Cornell University in 1961. He is past chair of the Fluorine Division of the American Chemical Society and has received the American Chemical Society's Award in Fluorine Chemistry.

Amos B. Smith III is the Rhodes-Thompson Professor of Chemistry at the University of Pennsylvania. He is an organic chemist whose research is focused on the synthesis of complex biologically active compounds and theoretically interesting unnatural products and novel materials. He was involved in the construction of a recently completed, new laboratory research building at the University of Pennsylvania. He received his combined B.S. and M.S. from Bucknell University in 1966 and his Ph.D. from Rockefeller University in 1972. He has served on numerous national editorial and advisory boards and has been chair of the Organic Division of the American Chemical Society (ACS) and is currently first editor-in-chief of the new ACS publication, *Organic Letters*. He has won awards including the Alexander von Humboldt Research Award for Senior U.S. Scientists, the ACS Ernest Guenther Award in the Chemistry of Natural Products, and the ACS Award for Creativity in Synthetic Organic Chemistry.

APPENDIX B

Statement of Task

The committee on the Design, Construction, and Renovation of Laboratory Facilities will provide guidance on effective approaches for building laboratory facilities in the chemical and biomedical sciences. The study will provide a framework of prudent practices for the members of the scientific community; the facilities managers and architects that work with them in constructing or modifying laboratories; the various federal, state, and local governmental bodies that must develop regulations and monitor compliance; and the federal agencies and private foundations that invest their limited funds in construction and renovation projects. The goal of the study is to provide guidance that can result in buildings that provide effective and flexible laboratories, are safe for laboratory workers, are compatible with the surrounding environment, have the support of the neighboring community and governmental agencies, and can be constructed in a cost-effective manner.

APPENDIX C

Committee Meetings

First Meeting, February 10-11, 1998

Presentations

Introduction of committee members and staff
Introduction to the National Research Council (NRC)
NRC expectations of its study committees
Discussion of Balance and Composition of the Committee
Discussion of Individual Bias and Conflict

Study Planning
- Scope of study
- Objectives of study
- Study approach Role of the staff

Discussion of laboratory planning and construction considerations
- Role of the user
- Role of the architect

Continuation of planning and construction considerations
- Regulatory considerations
- Stakeholder considerations

Identification of major issues in laboratory design/construction/renovation

Presentation and discussion of related studies
Rassa Davoodpour, National Institutes of Health
Jeanne L. Narum, Project Kaleidoscope

Second Meeting, April 13-15, 1998

Presentations

An Architect's View of the Laboratory Design Process
Todd S. Phillips, American Institute of Architects
Leo A. Phelan, Veterans Administration

An Administrator's View of Laboratory Design
Robert E. Burnett, University of Virginia

Presentation by the Princeton University Project Team
Allen Sinisgalli, associate provost; Gary H. Ireland, scientific construction; George J. Barker, building manager; Martin F. Semmelhack, scientist; Robert Schaeffner, architect (Payette Associates); Keith W. Stanisee, project management (Barr & Barr)

Presentation by Users—I
David J. Goldsmith, Emory University
Stephen L. Brenner, DuPont Merck Pharmaceutical Company
Steven W. Baldwin, Duke University

Presentation by Users—II
K. Peter Walter, University of California at San Francisco

Presentation by Users—III
Malcolm F. Nichol, University of California at Los Angeles
Frederick D. Lewis, Northwestern University
M. Tom Thomas, Pacific Northwest National Laboratory
Leonard D. Spicer, Duke University

Presentation by Design Professionals—I
P. Richard Rittelmann, Burt Hill Kosar Rittelmann Associates
David Harris, National Institute of Building Sciences

Presentation by Design Professionals—II
Victor Cardona, Smith Group
Michael Somin, Earl Walls Associates

Presentation by Regulatory and Code Agencies
Eric R. Rosenbaum, Hughes Associates, Inc.
James Pecht, U.S. Access Board
Patricia Weggel-Laane, Environmental Protection Agency

Third Meeting, June 16-17, 1998

Presentations

Review 1991[1] Workshop: Scope and Study Plan
Review of earlier meetings

- 1st meeting
- 2nd meeting

Review of outline

- Comparison with scope
- Adequacy

Substantive discussion of report

- Introduction
- Discussion of participants
- Discussion of Environmental Health and Safety issues
- Discussion of sociology
- Discussion of costs
- Discussion of design alternatives
- Discussion of strategy
- Discussion of community relations
- Discussion of resources
- Summary of report contents
- Discussion of writing assignments

Fourth Meeting, August 31, 1998 - September 1, 1998

Committee Deliberations

Fifth Meeting, November 4-6, 1998

Committee Deliberations

Sixth Meeting, January 28-29, 1999

Committee Deliberations

[1]Board on Chemical Sciences and Technology Workshop on Design, Construction, and Renovation of Laboratories, June 28-29, 1991, Washington, D.C.

APPENDIX D

Selection of a Design Professional

A research laboratory facility typically requires more time for design and construction, a larger capital expenditure, and higher operational costs than most other building types. Because of the highly technical and complex nature of research laboratory facilities, the design professional should be selected carefully and thoughtfully. An objective selection process should be developed so that a highly qualified design professional is selected. Fee and agreement negotiations typically follow the selection of this person. The Brooks Act of 1949 codifies this type of selection process, by which the most highly qualified design professional is selected prior to fee and agreement negotiations. However, if funds for professional design fees are limited, this should be disclosed at an early point in the process. Institutions that favor working with a local design professional may be at significant risk; the attractiveness of familiarity is generally not a reasonable substitute for appropriate experience. Conversely, if a more remotely located design professional is engaged, the extent and method of local oversight by this person should be established.

The selection process described below represents a formalized step-by-step procedure that should result in the selection of an architectural firm experienced in the appropriate building type and the assignment by the firm of individuals who have the appropriate qualifications for the project. Other less-formalized selection procedures can also be used; each institution should decide the most appropriate objective selection process. Some institutions may wish to use a design competition to select an architect. Although the amount of time and interaction generally associated with a design competition is only a fraction of the effort typically required to design as technologically and programmatically complex a facility as a research laboratory, it normally requires 12 to 14 months, as well as extensive interaction with the proposed users and institutional representatives. For this reason, most institutions do not use a competition for selecting the architect.

The selection process begins with the identification of a "long list" of potential candidates, usually by a selection committee, and proceeds through the request and review of qualifications, the development of a "short list" of candidates, the request and review of formal proposals, and interviews, to the selection of the most appropriate architectural candidate. The selection committee is typically composed of representatives from the administration (e.g., CEO, CFO), researchers (e.g., principal investigators and technicians), and physical plant and/or buildings and grounds representatives. One individual, often the client project manager, should be identified to oversee this process and be the single point of contact for the architectural candidates.

LONG LIST OF ARCHITECTS

Often, a "long list" of architectural candidates is developed by the selection committee after the institution has identified the project's need, program, and site. Some institutions, however, choose to begin selection of the architect before the project site is selected and before the project program is developed, as most architects are trained in site planning and some are experienced in developing detailed programs for research laboratory facilities. Other institutions engage a site planner and or programmer to complete a preliminary description of the overall project program and site. Each institution should decide the best time to begin the architect-selection process. The sooner the architect becomes familiar with the project, however, the sooner the architect will be able to assist the institution in the selection of a site, development of the project's program, and design of the research laboratory facilities that respond to its needs.

Once it has been decided to engage an architect, the institution develops a "long list" of potential architectural candidates. This long list can be anywhere from 7 to 15 architectural firms. Too short a list may not capture the best potential candidates, while too long a list may risk a cumbersome review process and discourage potential candidates from responding. The length of this list is determined by the number of potential candidates identified by the institution. Potential candidates should be identified by asking colleagues for referrals, contacting the American Institute of Architects, and checking with other institutions that have built science facilities similar to the anticipated project. The identification of the long list of architects can take anywhere from 2 to 4 weeks.

REQUEST FOR QUALIFICATIONS

Once the institution has identified the long list of architects, the selection committee should prepare a request for qualifications (RFQ). The RFQ should include a general description of the anticipated project, including its size, location, and stage of development (e.g., initial planning stages, just starting programming, ready to start design). The RFQ should also include established project requirements such as cost, schedule, program, design goals, project participants, background information, existing buildings if involved, and so forth. The RFQ should include a request for information about the architectural firm, including similar projects, history of the firm, size of firm, list of key individuals including resumes, list of references, list of awards, and the like. The purpose of this RFQ is to receive materials about each candidate that provide the institution with a better understanding of the firm's general qualifications. The information requested from the architect is generally information that the firm has prepared previously for similar requests.

It is important that the architect be provided with as much information as is available about the anticipated project so that the firm can provide the appropriate qualification information. Architectural firms may want to know more about the project, and a representative of the institution should be available to answer the architect's questions. Some architects may want to visit the site prior to the preparation of the RFQ package. Although tours of the campus should not be discouraged at this stage, giving tours to those architects who are identified on the subsequent "short list" would be more appropriate. The architect should be informed about the selection process as well as the criteria by which the institution will decide which firms are appropriate for the subsequent short list and interview process. Typically 2 to 3 weeks should be allowed for the architect to prepare a qualifications package.

SHORT LIST

After the selection committee has reviewed the qualifications of the long list of architects, a short list is developed by reviewing the qualifications packages based on prescribed criteria. This process often includes assigning values to various criteria, such as appropriate experience, references, organizational depth, size of the firm, and so on. Of all the criteria, appropriate experience is probably the most important. It can also be important to match the size of the firm with the size of the project. For instance, a smaller firm that has done only projects on the order of $1 million to $5 million may find a project of $10 million to $15 million a significant challenge. Similarly, larger architectural firms that typically work on $40 million to $100 million projects may find it difficult to give a $5 million to $10 million project appropriate attention. The short list typically consists of 4 to 6 architectural firms.

REQUEST FOR PROPOSALS

Once the short list of architects is developed, the selection committee should prepare a request for proposals (RFP). The RFP includes a detailed list of questions that the architect should answer in a formal proposal. An RFP typically includes questions such as the following:

- How will the architect approach this project?
- How will the architect establish priorities and make decisions?
- Who will be assigned to this project on a day-to-day basis, for overall management during the construction process?
- What are the qualifications of the individuals who will be assigned to this project?
- How does the architect typically establish a fee for a project?
- What does the architect deem to be the most important issues for consideration on this project?
- How does the architect manage schedule and costs during design and during construction?
- Who would the architect recommend as engineers and consultants?

It is appropriate to request detailed resumes of the individuals who will be assigned to the project, as well as references for those individuals.

Some institutions have found it helpful to include as part of the RFP a draft of an Owner/Architect Agreement prepared by the institution. Other institutions have chosen to provide a standard Owner/Architect Agreement produced by the American Institute of Architects (AIA-B141 Standard Form of Agreement between Owner and Architect) and ask each architect to provide a list of the modifications he or she would typically make to this standard document.

Some institutions may ask the architect to prepare a formal fee proposal. If a formal fee proposal is requested, it should be understood that this represents only a guideline for the institution to compare with that of other architectural firms. It is difficult for an architect to estimate accurately the services that will be required by a project at such an early stage, and therefore it is difficult to project a fee accurately. It is appropriate, though, to request that the architect provide a description of how the fee would be established and what services the architectural firm includes within its standard scope of services. The RFP should include the names of the other architects that the institution is considering so that each architect can decide whether to proceed with the selection process. In general, the preparation of a proposal, particularly one responding to a formal RFP prepared by an institution, requires a substantial effort on the architect's part. This is particularly true if the architect decides to visit the site, which will require travel expenses and time in addition to that needed to prepare the RFP.

An architectural firm usually will expend a significant amount of time and energy on the preparation of a proposal once it has made the short list. Typically, 3 to 4 weeks is allowed for the architect to prepare a proposal.

INTERVIEW

Once the selection committee has received the proposals from the short list of architects, it should review and rank the proposals, using a method similar to that used in reviewing the qualifications package sent in response to the RFQ. The selection committee may choose to reduce the number of candidates or to interview all candidates on the short list. At this point, the architects should be encouraged to visit the site, if they have not done so, and to review the project details with the appropriate representatives on site. In addition, for major projects the selection committee may wish to visit facilities built previously by the architects on the short list. Prior to the interview, the selection committee may develop a list of questions and issues that it would like the architect to address. This may simply be the list of questions and issues developed as part of the RFP, or alternatively, a list of questions and issues developed specifically for the interview.

The interview typically includes a presentation by the architect of projects he/she has developed that are similar to the anticipated project. The interview may also include a description by the architect of the process that would be used to develop this project program, identify the project site, develop the design, collaborate with the institution, manage the schedule and costs, and administer the construction contract. A sufficient amount of time should be allowed for the architect to present qualifications and ideas, and also for the selection committee to ask the architect questions about the project. On average, a presentation lasting 45 minutes followed by a 45-minute question period is adequate. Prior to the interview, the selection committee should develop selection criteria that allow each member of the selection committee to record thoughts and evaluations during and immediately after each interview. As much as possible, interviews should be scheduled for the same day, or for two consecutive days, to minimize the amount of time between the first and last interviews. It is essential that those individuals who will be assigned to the project be present at the interview.

Some selection committees visit similar projects completed by the architect. References should be contacted before or immediately following the interviews. Shortly after the interview, the selection committee should meet to discuss its impressions and observations and to decide as quickly as possible which architect is the most appropriate for the project.

Personalities and human chemistry form an important part of the decision-making process. The institution and the architect will be working together for an extended period, and it is important that the design team and the institution's representatives form a constructive working relationship.

FINAL SELECTION

Once the institution decides to engage an architect, the amount of time needed to develop the long list (in order to prepare the RFQ, review qualifications packages, develop the short list, develop the RFP, review proposals, interview architectural candidates, call references, and decide on the appropriate choice) can range from 12 to 16 weeks. This process requires the focused attention of the selection committee and especially that of the individual designated to oversee and manage the process.

After the selection committee has made its decision, the architect selected should be notified, as should those who have not been selected. If ratification by a higher authority is required and may delay prompt notification, a letter of intent or other similar document should be prepared and executed to formalize the working relationship until a formal agreement can be executed.

Appendix E

Definitions

TERMS

Americans with Disabilities Act—Law mandating that facilities should provide, or be capable of being easily modified to provide, reasonable accommodation for qualified workers with disabilities.

As-builts—Construction documents on which are recorded all changes made during construction.

Benchmarking—Comparing proposed with existing facilities by obtaining information on similar existing facilities.

Building code—A code applicable to buildings, adopted by a government body, and administered with the primary intent of protecting public safety, health, and welfare; generally includes both review and approval process requirements and specific technical standards.

Building commissioning—A process that gives the owner assurances that a building will perform, in the short term and over the life of the facility, as designed.

Building permit—Authorization by a government body for construction of all or part of a building, or installation of a utility. Signifies that the governing body has reviewed the construction documents and given approval. Inspectors monitor construction and sign the permit when all construction meets building codes.

By-pass hood—A fume hood design in which there is an opening above the sash through which air may pass at low sash position.

Central utility shaft—A horizontal or vertical central shaft within a building used to run ventilation ducts, plumbing, and electrical services.

Champion—Person who articulates the need for a project and drives the project from beginning to end.

Change order—Any modification to the original construction documents.

Client budget authority—A person who has been appointed by a senior financial administrator and can authorize major budget changes.

Client project manager—A member of an institution's in-house architectural or engineering team who derives authority from the head of facility operations.

Client user representative—A person who represents scientist-users. He or she is appointed by a senior administrator such as a dean or a director of research. This person is knowledgeable about the functional use of the facility and knows many of the ultimate users of the facility. Also referred to as user representative.

Client team—Composed of the client user representative, client project manager, and client budget authority. This team stays intact from predesign through post-construction and maintains continuity in the scope and execution of the construction project.

Code—A collection of laws, regulations, ordinances, or other statutory requirements adopted by government legislative authority. Some professional and trade organizations have published advisory documents that they term "codes," but these documents do not have the force of law (unless adopted by a government body) and therefore are actually collections of promulgated criteria and standards, rather than codes.

Conditions assessments—Formal and informal processes providing building information for facility programs. Information may include immediate building needs, highlight building deficiencies for short-term and long-range projects, and present program information in terms of building requirements.

Delivery service corridor—Corridor designated for deliveries, not for movement of people.

Design team—Members of the design group (design professional, engineers, and specialty consultants) and client group who work together to program construction or renovation.

Elevation—A flat scale drawing of the front, back, or side of the interior or exterior of a structure.

Existing conditions—Documented current physical state of a facility to be renovated or replaced.

Facility evaluation—Assessment of the existing condition of a facility.

Facility inventory—Set of as-builts, drawings showing existing conditions, list of deferred maintenance items, and other documents detailing existing facility.

Facility program—Detailed description of the function, area, utility, and environmental requirements for a project.

Flexibility—Ability of a facility to be easily modified to support varied research.

Floor loading—Weight (per square foot) a floor can support.

Floor plate—Floor area corresponding to the structural grid of a building.

Floor-to-floor height—The distance between floors, including the space between floors for utilities, ceilings, flooring, and the like.

Footprint—The exterior dimensions of a building.

Generic laboratory design—A design in which similar elements are similarly arranged within each laboratory space.

Gross square feet—Measure of area bounded by the outside faces of exterior walls.

Interaction diagram—A diagram used to rate the relative importance of interactions among different individuals and groups.

Interstitial floor—Service floor between laboratory floors that provides dedicated space for mechanical, electrical, and plumbing equipment and distribution systems.

Laboratory programmer—Design professional specializing in laboratory design; may or may not be an architect.

Life-cycle cost—Costs incurred over the life cycle of a building system, a piece of equipment, or an entire building.

Make-up air—Air required to maintain the code-required balance between (relatively) negatively pressured laboratories and positively pressured corridors.

Manifold exhaust system—An exhaust system in which the intake of many, or all, fume hoods is combined in one or more large manifolds and then exhausted through a single exhaust stack.

Master plan—An overall long-range plan for the land use of an institution.

Mechanical, electrical, and plumbing—Utilities needed to service a building.

Modular design—A technique that uses a standardized size module as the fundamental unit for space planning. Larger spaces comprise multiple modules.

Net square feet—Measure of the area bounded by the inside finish of the outer walls and the inside finish of permanent partitions.

Open laboratory—Laboratory in which a large open space and common equipment rooms are shared by several researchers or even research groups.

Operations and maintenance manuals—Manuals that detail information about the operations and maintenance of all laboratory systems and equipment.

Postoccupancy evaluation—The process of surveying and analyzing recently completed and occupied facilities, preferably after the first year of operation, to provide the owner, and others involved with a construction or renovation project, a determination of how the building is performing and a review of the organization of participants and process for the construction or renovation.

Project leader—Client's single point of contact within the client group and with the design and construction groups for a project. He or she has operational authority and responsibility for the project.

Project team—Group of participants involved throughout the project. Includes client team, design professional, and general contractor.

Record drawings—Construction documents on which are recorded all changes made during construction.

Service corridor—Within a building, a horizontal passage of two types: the utility service corridor and the delivery service corridor.

Strategic plan—Long-range and large-scale operational plan for an institution that encompasses both the physical plant and organizational plans.

Structural grid—Horizontal spaces between the structural members (beams) of a building.

User representative—*See* client user representative.

Utility chases—Vertical shafts within a building used to run ventilation ducts, plumbing, and electrical services vertically within a building.

Variable air volume hood—Fume hood for which the airflow is regulated to maintain a constant face velocity.

Zoning—The system of local land-use regulations.

ACRONYMS

A&E	architectural and engineering
ADA	Americans with Disabilities Act
AHJ	agencies having jurisdiction
BOCA	Building Officials and Code Administrators International
CAA	Clean Air Act
CAV	constant air volume
CUPs	central utility plants
EH&S	environmental health and safety
EIA	environmental impact assessment
EIS	environmental impact study
EPA	Environmental Protection Agency
FF&E	furnishings, fixtures, and equipment
GMP	guaranteed maximum price
GSF	gross square feet

HAP	hazardous air pollutant
HEPA	high-efficiency particulate air (filter)
HVAC	heating, ventilation, and air conditioning
ICBO	International Conference of Building Officials
MEP	mechanical, electrical, and plumbing
NASF	net assignable square feet
NMR	nuclear magnetic resonance
O&M	operations and maintenance
OSHA	Occupational Safety and Health Administration
POE	post-occupancy evaluation
RCRA	Resource Conservation and Recovery Act
RF	radio frequency
RFP	request for proposal
RFQ	request for qualifications
SBCC	Southern Building Code Congress International
VAV	variable air volume

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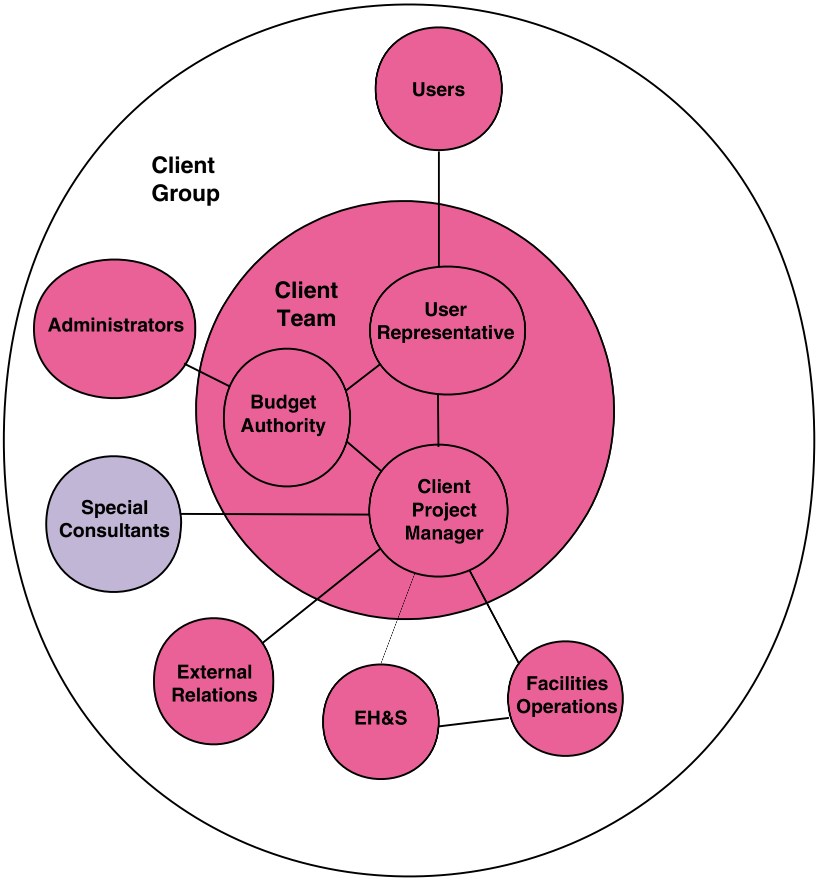

FIGURE 1.1 Members of the client group and their lines of communication. The members of the client team—who are representatives of the users, the financial office, and the facilities operations group—are intimately involved in all phases of a laboratory construction or renovation project. The client group is composed of the client team and all other members of the institution who are involved in the project, such as the users, campus architect, environmental health and safety (EH&S) officer, and the external relations office. This group also includes special consultants, such as a construction manager and site assessor, who are hired by the client. Users communicate with the client team through the user representative. All other communication within the client group, including that with consultants, is through the client project manager, with the possible exception of communication between the EH&S officer and the facilities operations group. The colors assigned to the members of this group—red for members of the institution, purple for consultants—are used in the communication figures in Chapter 2.

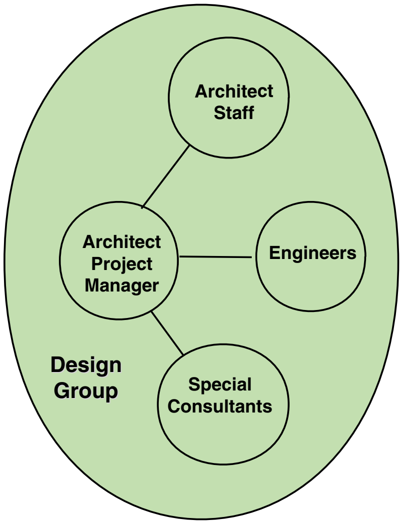

FIGURE 1.2 Members of the design group and their lines of communication. The members of the design group are the architect and other design professionals, such as laboratory programmers, engineers, and specialty consultants hired by the design firm (e.g., fire specialists, environmental consultants, and code consultants). All communication within this group is through the architect project manager. The color for this group—green—is used in the communication figures in Chapter 2.

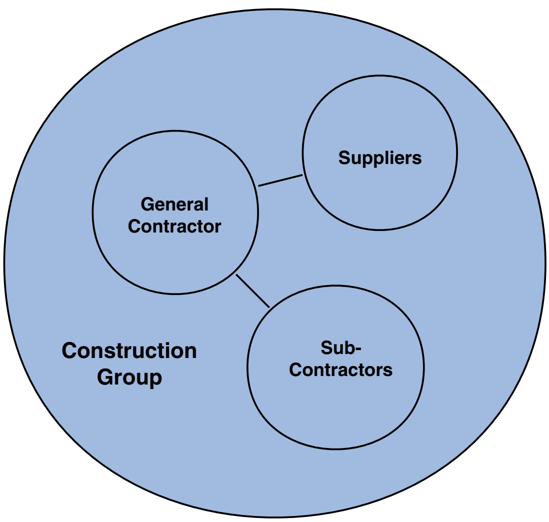

FIGURE 1.3 Members of the construction group. Members of the construction group are the general contractor and the subcontractors, and may also include suppliers. The color for this group—blue—is used in the communication figures in Chapter 2.

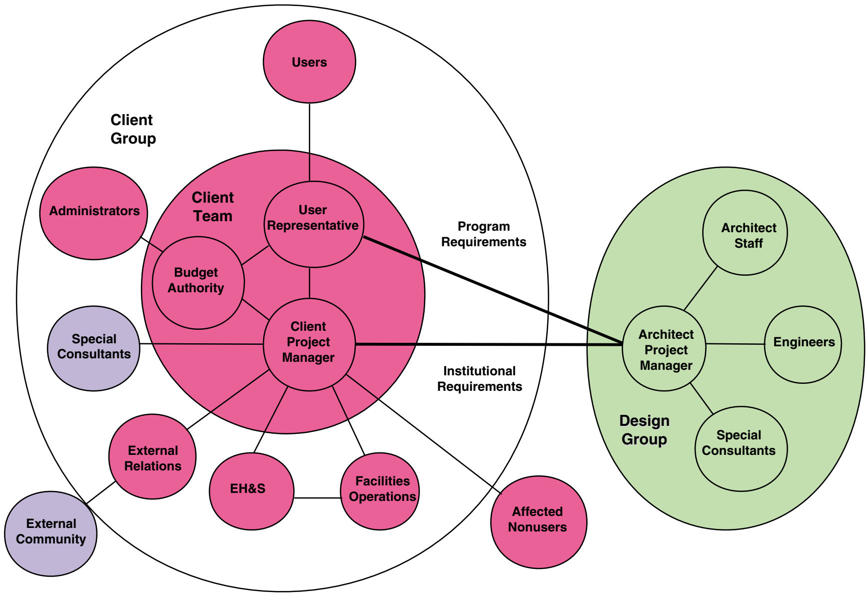

FIGURE 2.2 Participants involved in predesign phase activities and their lines of communication. The client team is central to all communications within the client group. The users communicate with the client team through the user representative; all other client communication with the client team is through the client project manager. The external community communicates with the client team only through the external relations office. Communications between the design and client groups in this phase of the project are between the architect project manager in the design group and, depending on the issue, the user representative or the client project manager of the client team. It is essential that these primary points of contact be respected. Red = client group, green = design group, purple = external members of client group.

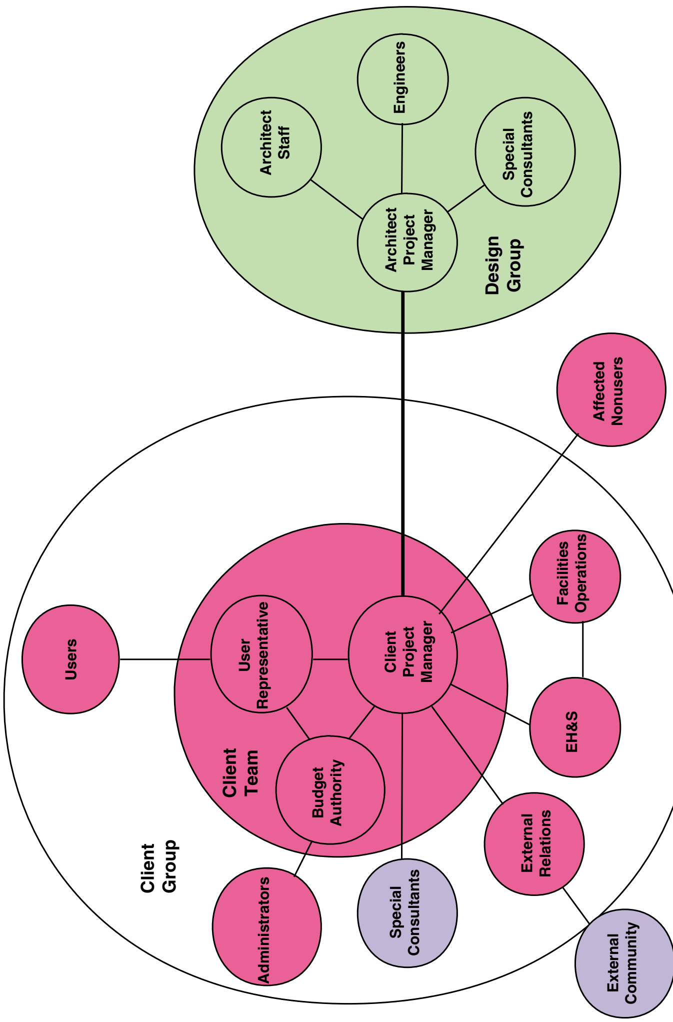

FIGURE 2.3 Participants involved in design phase activities and their lines of communication. The client team is central to all communications within the client group. The users communicate with the client team through the user representative; all other client communication with the client team is through the client project manager (PM). The external community communicates with the client team only through the external relations office. This phase differs from the predesign phase in that all communications between the design and client groups are between the architect project manager and the client project manager. It is essential that these primary points of contact be respected. Red = client group, green = design group, purple = external members of client group.

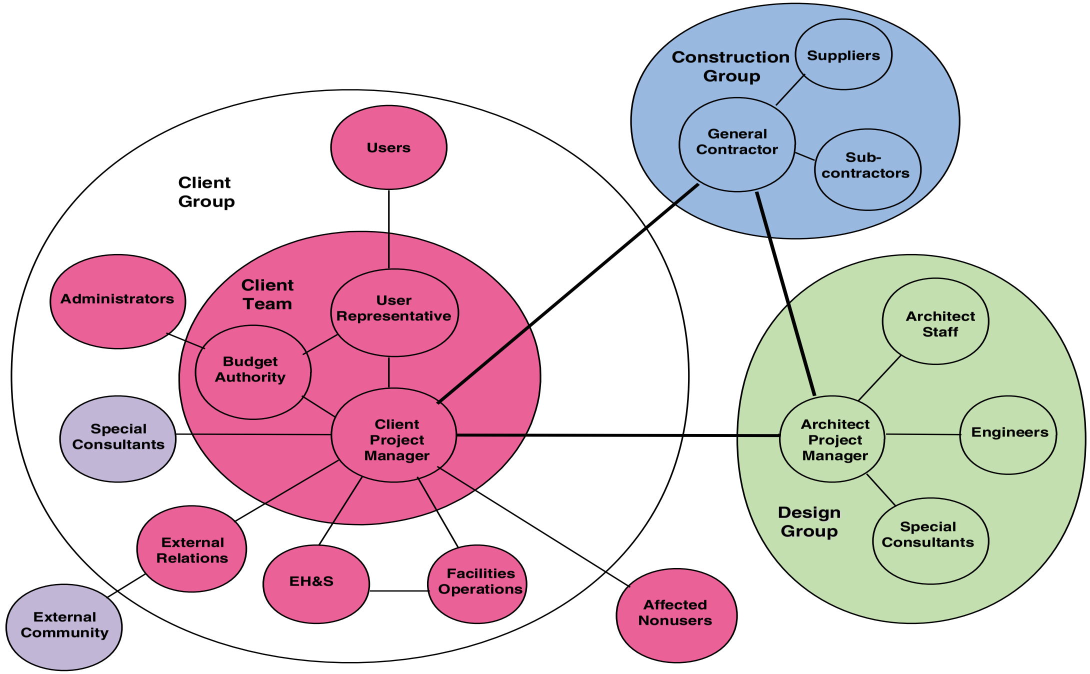

FIGURE 2.4 Participants involved in construction phase activities and their lines of communications. The client team is central to all communications within the client group. The users communicate with the client team through the user representative; all other client communication with the client team is through the client project manager (PM). The external community communicates with the client team only through the external relations office. Communications between the client, design, and construction groups are only between the general contractor, the client project manager, and the architect project manager. Because of the large number of participants in this phase of the project, it is essential that these primary points of contact be respected. Red = client group, green = design group, purple = external members of client group, blue = construction group.

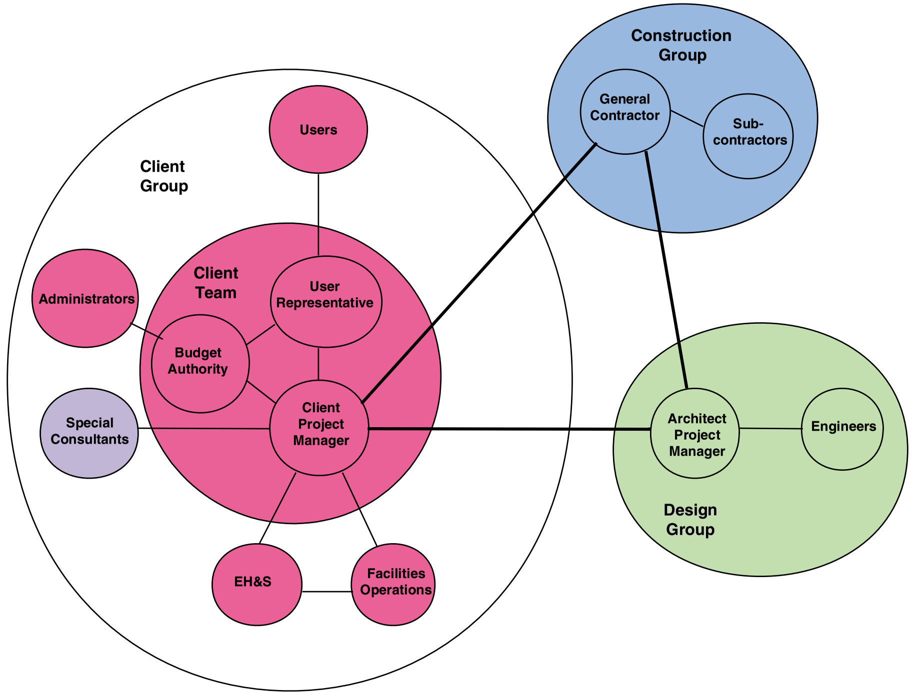

FIGURE 2.5 Participants involved in postconstruction phase activities and their lines of communications. The client team is central to all communications within the client group. The users communicate with the client team through the user representative; all other communication with the client team is through the client project manager. The external community communicates with the client team only through the external relations office. Communications between the client, design, and construction groups are conducted between the general contractor, the client project manager, and the architect project manager. Because of the large number of participants in this phase of the project, it is essential that these primary points of contact be respected. Red = client group, green = design group, purple = external members of client group, blue = construction group.