10

Facility Design and Physical Containment

One of the most important goals of the design of the biomedical laboratory is to prevent the release of hazardous biological agents from the laboratory. This goal, usually called physical containment, is achieved by following prescribed laboratory practices, by employing special equipment such as the biological safety cabinet, and by incorporating special design features in the facility itself. Laboratory practices were discussed in Chapters 1 through 8, and Chapter 9 covered the use of HEPA filters and biological safety cabinets. In this chapter we will discuss those elements of facility design that are needed for physical containment.

The well-designed facility can help promote safety and safety awareness while providing important features needed to achieve physical containment. Choosing the appropriate containment equipment is an important part of facility planning, but equipment or facility design alone will not suffice to assure a safe facility. Neither will safe practice alone, although safe practice is a major component of containment.

As the potential hazards of the research increase, the importance of proper facility design also increases. If work with hazardous biological agents must be performed at a higher level of containment than the current facility design permits, some design changes will be required. Research with agents of moderate to high hazard (see Chapter 11) must only be performed in facilities that are designed to minimize the risk to workers, the community, and the environment.

The types of research for which biological containment guidelines or statutory regulations exist primarily involve work with etiological (disease) agents, oncogenic (cancer) viruses, and recombinant DNA molecules. Research involving these biohazards must be conducted at the level of physical containment dictated by the appropriate government regulations. We will discuss these requirements more fully in Chapter 11, but for the purposes of this chapter, facilities designed to meet containment criteria can be classified into four levels:

1. the basic facility
2. the modified basic facility
3. the partial containment facility
4. the total containment facility

In this classification the basic facility is used for work with the least hazardous agents and the total containment facility is used for the most hazardous agents. For recombinant DNA research, the biosafety levels of these facilities have been abbreviated as BL1, BL2, BL3, and BL4 (previously called P1 to P4); these terms are also used to refer to the corresponding facilities for other kinds of biohazard research (see Section 11.4). Table 10.1 indicates the level of facility that is appropriate for work with cancer viruses, recombinant DNA, and human pathogens.

In this chapter we will only discuss the physical design of the first three levels of facilities. We will not discuss the design of facilities intended for total containment, as this topic is

S. R. Rayburn, *The Foundations of Laboratory Safety*

TABLE 10.1 Facility designations for various hazardous agents*

Hazardous agent type	Level of facility		
	Basic or modified basic	Partial containment	Total containment
Cancer viruses	Low risk	Moderate risk	—
Recombinant DNA molecules	BL1 (P1), BL2 (P2)	BL3 (P3)	BL4 (P4)
Human pathogens	BL1, BL2	BL3	BL4

*The classification of hazardous agents is discussed in Chapter 11.

highly specialized and excellent resources are available (31, 32, 155, 378). The facilities that are most common in organizations where biomedical research is conducted are the two basic facilities (BL1 and BL2); in addition, some institutions have research projects which require that the work be conducted in a partial containment facility (BL3). In the following pages we will examine the basic features and design characteristics of such facilities.

10.1 Primary and Secondary Barriers

Physical containment of biohazards is achieved through the use of primary and secondary barriers. **Primary barriers**, the "first line of defense" against the release of a biohazardous agent, are the measures used to contain the experimental material, and include both techniques and equipment. In the context of this chapter, however, they refer to the use of items of equipment, particularly safety cabinets. Primary barriers are used to provide physical separation of the worker and experimental materials to prevent injury to the worker, provide physical separation of the experimental work from the environment to prevent contamination of the work, and control the release of aerosols created by the work which could pose a hazard for the researcher.

Primary barrier devices must possess certain characteristics that increase their efficiency at achieving containment.

- *Volume.* These devices should minimize the volume of contained material which will become contaminated.
- *Transfer.* They should provide for safe, convenient transfer of working materials into and out of the device.
- *Decontamination.* These devices should be capable of being decontaminated in a convenient way after use.

Examples of some devices which meet only the first criterion are the safety blender (Figure 10.1), centrifuge safety tubes (Figure 10.2), and flexible film containers (Figure 10.3). These devices do limit the amount of material used and contained, but they do not allow easy transfer or decontamination. Therefore, they are not true primary barriers; however, they do provide the best possible containment available for mixing and centrifuging operations. The most familiar primary barrier device that meets all three criteria is the **biolog-**

FIGURE 10.1 The safety blender contains aerosols and controls leakage around the impeller shaft. (Courtesy of Waring Products Div., Dynamics Corporation of America.)

FIGURE 10.2 Sealed safety tubes for centrifugation minimize the risk of aerosol creation. (Courtesy of Beckman Instruments, Inc., Spinco Division.)

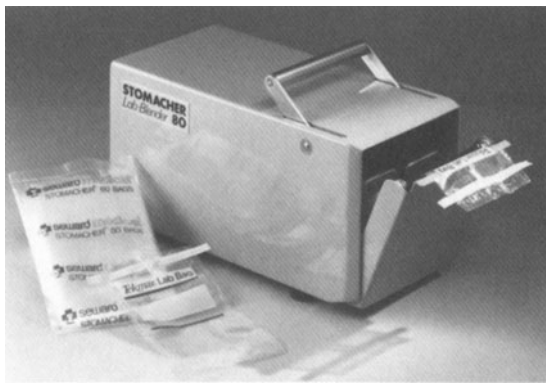

FIGURE 10.3 Flexible film containers make it possible to mix liquids without producing aerosols. The Stomacher® Lab Blender is a registered trade mark of Seward Medical, Ltd. (Courtesy of the Tekmar Company.)

ical safety cabinet (see Chapter 9). HEPA filters and special centrifuge cabinets can also be used as primary barriers (see Figure 1.8).

The **secondary barrier** against biohazard release is generally considered to be a back-up to the containment provided by the primary barriers. Secondary barriers comprise facility layout and design, and are intended to prevent the escape of the agent from the laboratory rather than to protect the worker (Figure 10.4). These barriers consist of such features as ventilation control (filtration, directional air flow), controlled access zones, limiting traffic into laboratories, control of movement of research materials, and similar design or procedural features. Facility design is a complex subject, so we will only consider some basic concepts that must be recognized when planning a facility. Also, we will only discuss modification of existing structures, since a discussion of new laboratory construction is beyond the scope of this text.

Architectural features

The construction features of a building are very important in determining suitability of a laboratory for work with biohazards. The person who must make the determination needs to ask the following questions: Are the walls, ceilings, and floors impermeable to liquids? Do any structural cracks exist? Are walls, ceilings, or floors penetrated by poorly sealed or unsealed pipe chases or open holes? If so, can they be sealed? Can walls, floors, and ceilings be easily cleaned? Are windows, doors, or other penetrations to the exterior of the laboratory capable of being closed and sealed? Can lighting fixtures collect dust and contamination? Are there any horizontal overhead pipes or other utilities which can also collect contamination? Are all horizontal surfaces capable of easy cleaning?

Other important features to consider are the arrangement of corridors, doors, and rooms and the traffic patterns. Are corridors arranged to allow separation of clean areas from contaminated areas? Can existing entry doors be made into vestibules or airlocks if necessary? Does the building layout permit installation of locker rooms with shower and clothing change facilities, if required? Are office areas separated from contaminated areas? Will the locations of individual laboratories be appropriate, once the locations of special facilities such as autoclave and glassware washing areas, animal facilities, storage rooms, and preparation areas are determined?

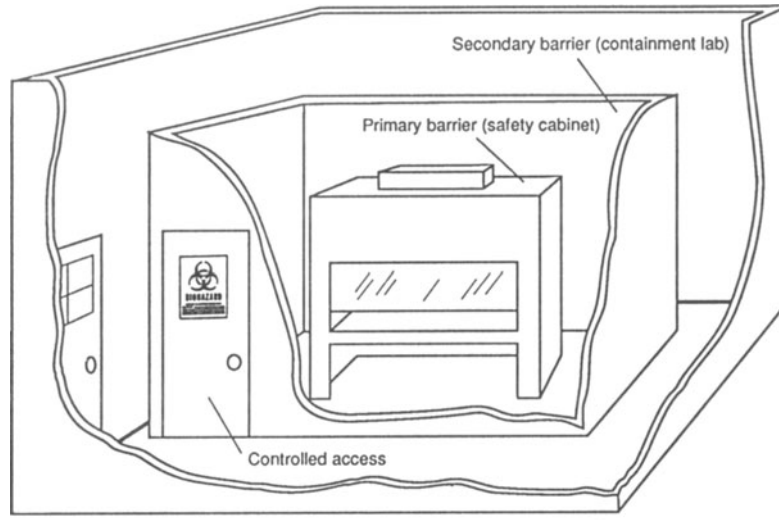

FIGURE 10.4 Primary and secondary barriers. This illustration shows the relationship between the primary and the secondary barriers.

Air, water, sewage, and vacuum systems

In order to design a laboratory suitable for physical containment the ventilation, water supply, and waste (sewage) systems must meet certain requirements. The design of these systems for containment work, especially in existing buildings, is quite complex. The **ventilation system** must be designed to ensure that air flows from "clean" areas or areas of least hazard toward areas of highest level of hazard or required containment. This design principle is known as *directional air flow.* This means that if feasible the highest level of negative static pressure must be in areas of greatest potential contamination.

There must be enough air exchanges in the laboratory area, and laboratory air must not be recirculated to the supply system as makeup air: that is, laboratory exhaust air must not be recirculated back into either the containment area or the rest of the building, even if the exhaust air is HEPA-filtered. Some regulations may require HEPA filtration of exhaust air from the facility regardless of the fact that it will not be recirculated. It is also necessary to determine the location and direction of the building's air and fume-hood exhaust discharge to ascertain that the air intake will not draw exhaust air back into the building, under all conditions of ambient atmospheric pressures and temperatures, wind direction, or other weather factors (256).

Domestic **water supply** to laboratories may require installation of "back-flow preventers," special devices that provide positive protection against siphoning laboratory water into the potable water system should the supply pressure drop. Building drinking fountain, cafeteria, and rest room water supplies must be on the potable water supply rather than the laboratory water supply system. Unfortunately, this is not the case in many existing laboratory buildings.

Laboratory **waste water** can be handled in various ways. Special "acid waste" systems that utilize neutralizing tanks and are separate from the sanitary waste system are found in many modern research buildings. For work with very hazardous agents waste water should be heat-treated before it enters the ordinary waste system.

Finally, building **vacuum systems** must have liquid traps designed to prevent biohazardous agents from contaminating the vacuum lines and pumps. Such traps should be "fail-safe," shutting off the vacuum before liquid enters the building system. A device similar to the lower illustration in Figure 1.7 can be used.

10.2 Designing Basic and Partial Containment Facilities

The specific engineering features incorporated into the design of a laboratory depend upon the highest degree of hazard that is likely to be encountered in the research. In new facilities, these engineering features are included in the design. In the modification of existing facilities, some of these features can be readily installed while others may require more extensive renovation as well as the services of a safety consultant and an architect specializing in the design of containment laboratories. For the purposes of this text, we will limit our discussion to laboratories at the three most common levels of containment: the two basic (basic and modified basic) facilities and the partial containment facility. A discussion of the maximum containment facility is beyond the scope of this text.

The **basic facility** usually consists of a general laboratory with certain design features and operational practices intended to limit the possibility of exposure to and release of biohazardous agents. However, no containment equipment is required and specialized ventilation systems are unnecessary. The facility must be checked to be certain that it does indeed provide for sufficient control and containment of any agent to be used.

In a basic facility most research work is conducted on the open bench using standard microbiological techniques. Techniques that may result in the production of aerosols should be minimized. If the agents being used have hazards that warrant additional containment, the work should be performed in a biological safety cabinet. When this higher level of containment is required, the laboratory is called a **modified basic facility**. Although no special engineering features are needed in either of these laboratories, the physical layout of the facility is important. Operations producing contamination, such as animal rooms or autoclave rooms used for decontamination of research materials, should not be located so close to the research or preparation areas that cross-contamination problems can occur. While not mandatory, office areas and areas that are frequented by nonlaboratory workers or the public should be physically separated from these laboratories.

The design of both kinds of basic laboratories should facilitate good housekeeping. The walls should have a smooth, impermeable finish that can withstand detergent solutions. The floors should be free from structural cracks, loose tiles, or crevices that prevent cleaning and allow buildup of contamination. Laboratory furniture should be structurally sound and easily cleaned, and bench tops should be impervious to chemicals and moderate heat.

Laboratory doors should be equipped with self-closing devices and should be marked with signs indicating the hazard(s) contained inside the laboratory and emergency contact information. If work involving hazardous agents will produce aerosols, a ventilated safety cabinet appropriate for the work should be available. Air from this cabinet should be passed through a HEPA filter and exhausted to the outside of the building. However, if the cabinet exhaust contains an integral HEPA filter, the exhaust may be discharged back into the room. Although modern laboratory design standards do not permit recirculation of laboratory exhaust air, older facilities may employ recirculated general exhaust air within the basic facility laboratory. However, unless the ventilation system in such older facilities is altered to eliminate exhaust recirculation, these facilities may not be upgraded to a higher level of containment.

Other typical features of the two basic facilities include a clean area provided within the laboratory itself solely for hand-washing purposes, and, if infectious materials are used in the facility, an autoclave. This need not be physically located in the laboratory, as long as it is available within the facility or building.

A typical **partial containment facility** is a specially engineered laboratory designed to handle moderately hazardous materials without unnecessary exposure or release of biohazardous agents. Various government agencies have published specific guidelines for

research with various agents at the "moderate risk level" (378), i.e., for etiological agents, for oncogenic viruses, and for recombinant DNA research. Work with these agents requires the use of partial containment facilities (see Table 10.1). Such facilities must be certified by the institution's biohazard committee as part of the administrative requirements for complying with federal rules for funding of research involving work with these materials. Unique features distinguishing the partial containment facility from the basic and modified basic facility include a specially engineered ventilation system and access control measures that provide a secondary barrier to the release of hazardous agents outside the controlled area.

Because of the nature and cost of construction of these facilities, most are designed for use as a central research resource and service facility for several laboratories or departments. The **architectural features** of the partial containment facility should include impermeable walls, floors, and ceilings. The finishes on these surfaces should allow cleaning with detergents. All wall, floor, and ceiling penetrations must be sealed so that space decontamination can be performed. Lift-out tile ceilings are not permitted, and lighting fixtures or horizontal utility runs that are collectors of dust and contamination must be avoided. Windows must be sealed in the closed position. Doors must be provided with self-closing devices and posted with hazard identity and emergency contact information. Facilities for handwashing must be located near the entry to the laboratory, and the taps should be of the foot, elbow, or electronically actuated design to prevent recontamination of clean hands by touching a contaminated hand valve.

Restricting access

Preventing unauthorized personnel from entering the facility, i.e., **access control**, can be achieved by a double set of entry doors—an "air lock"—or by another entry control feature, such as a locked door, that restricts access from the entry corridor into the containment area (see Figure 10.4). An air-lock design also prevents drafts from the corridor from influencing air flow patterns in the laboratory. Secondary containment within the area is achieved by designing the **ventilating system** to maintain directional air flow from outside the containment area into the containment area. For this purpose air balance in the containment area must be set to maintain an infiltration rate of at least 1.4 cubic meters per minute (m^3/min), or 50 cubic feet per minute from the corridor to the containment area. Figure 10.5 illustrates the proper air flow balance for a partial containment facility.

In order to ensure that air constantly flows from areas of least hazard or lowest relative contamination toward areas requiring the highest level of containment, the static pressures of the various rooms in the containment suite should be balanced so that the highest level of negative static pressure is in areas of most potential contamination (e.g., virus handling rooms). The building supply air provided to the containment laboratory may come from the same source as the air to other areas in the facility or building, provided that the exhaust air is not recirculated. General exhaust air from the partial containment laboratory need not be passed through filtration or other treatment before discharge to the outdoors. However, if filtration of exhaust air is necessary for special hazards, a prefilter and a HEPA filter should be utilized. The HEPA filter bank should be located as close to the facility as possible, and should be of the "bag-in/bag-out" design. Ducts, registers, and louvers must all be arranged to minimize drafts in sterile areas while allowing air flow at full design velocity. Inlet air to the facility should be prefiltered by passage through a conventional high-efficiency (85 to 95 percent or greater retention efficiency) filter.

The partial containment facility laboratory requires a ventilated safety cabinet, usually a biological safety cabinet, in every laboratory. It is good practice to exhaust the cabinet through its own ductwork directly to the outdoors; however, connection to the general exhaust or fume hood exhaust is also permissible. In either case, care in maintaining ventilation balance is extremely important.

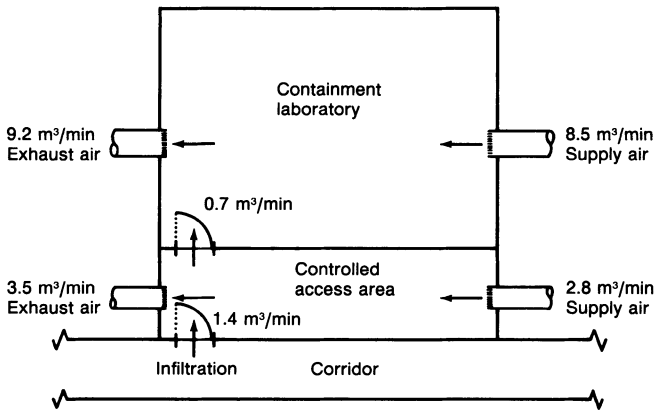

FIGURE 10.5 Directional airflow. The proper airflow balance for a containment laboratory is shown here, illustrating directional airflow and the use of air infiltration to prevent the escape of contaminants from the laboratory.

	Air balance (m³/min)	
	Supply	Exhaust
	8.5	9.2
	2.8	3.5
	1.4	
Total	12.7	12.7

No installation should ever permit the exhaust duct from a safety cabinet to become pressurized.

As in the basic facility, an autoclave is necessary if research involves infectious agents. The autoclave need not be located in the laboratory or in the partial containment facility, but must be located within the building. If contaminated materials must be transported outside the controlled area for autoclaving, appropriate precautions must be taken to avoid release of hazardous agents.

This is only a sketch of the types of features generally found in the partial containment laboratory, and is not meant to include all of the engineering features that may be incorporated into the design of such a facility. Excellent treatments of this subject are available (31, 32, 155, 378), and consultation services can be identified with the assistance of government agencies.

10.3 Safety Procedures in the Partial Containment Facility

As we discussed at the beginning of this chapter, physical containment requires more than just the use of a properly designed facility and special containment equipment. It also requires that all laboratory workers follow safe procedures and use proper techniques. Workers in the two basic facilities usually need only to observe good microbiological techniques. However, research in the partial containment facility requires a higher level of operational control. To accomplish this, every facility should have an operating procedures manual. This manual should describe the proper way to perform every laboratory procedure, and the operation of each of the major pieces of equipment should be detailed (228).

If a permanent technician is assigned to the facility, he or she may be made responsible for its operation and for the use of the facility by outside personnel. Such workers should learn how to use the equipment, particularly the biological safety cabinet. Copies of a pamphlet, such as *Effective Use of the Biological Safety Cabinet,* obtainable from the Division of Safety, U.S. National Institutes of Health, should be kept for reference and be given to cabinet users; see also Chapter 9. Facility policy also should dictate how radioactive materials may be used in the facility.

Personal practices

In addition to the practices described in Chapter 3, the following special precautions and practices must be meticulously observed for the protection of the worker, the experiment, and the other users of the facility:

- A biohazard warning sign must be displayed outside the laboratory at all times. When

work at the BL3, or moderate risk, level is being conducted, a notice must be posted limiting access to the laboratory (see Figure 10.6).

- Effective housekeeping measures must be strictly enforced. The laboratory must be kept free of dust-collecting objects, should not be used for storage, and the floors and counters should be cleaned frequently.
- Particular attention must be paid to disinfection of work surfaces before, after, and at intervals during work in the laboratory. Thorough wiping with 70 percent ethanol should be the minimum requirement.
- Unnecessary activity in and around the immediate work area during sterile procedures must be avoided.
- Workers in the laboratory must wear wrap-around lab coats and gloves when engaged in work at the low or moderate risk level. Hands shall be washed before and after work with a good germicidal soap. It is also good practice to change gloves periodically during work. Hands can be washed at these times. Most workers should wear double gloves to minimize the chance of contamination caused by a hole in a glove. Gloves and lab coats used in the facility must not be worn outside the facility. Gloves must be removed and/or changed before handling the telephone, centrifuges, doorknobs, etc. In fact, it is best to avoid handling the telephone. "Hands-free" telephones are available which have detached speakers. Use of this type of telephone avoids the face-hand proximity of the normal phone and possible contamination is minimized.
- No mouth pipetting is allowed.
- Biowastes and used materials must be promptly removed and prepared for decontamination (see Chapter 5). Pathogen-containing liquid wastes and recombinant DNA materials shall be autoclaved before disposal. CAUTION: Autoclaving of radioactive materials may be prohibited by local policy. Contaminated media should be treated with 1 percent chlorine bleach and 2 percent iodophor solution if this disinfectant will not react with the materials to be decontaminated.
- Blenders, homogenizers, mechanical pipetters, etc. must be used inside biological safety cabinets. Aerosols must be allowed to settle after use of this equipment, and the equipment and area must be decontaminated as required when the operation is finished. Pipetting can produce as much as 1.5×10^4 droplets (10 micrometers or less in diameter) per cubic centimeter. (Droplets of this size can be inhaled.)
- See Appendix I for a discussion of how to handle accidental spills.
- Workers must be instructed to think about their work, to set aside sufficient time to complete the task, and not to allow interruptions to interfere with it.

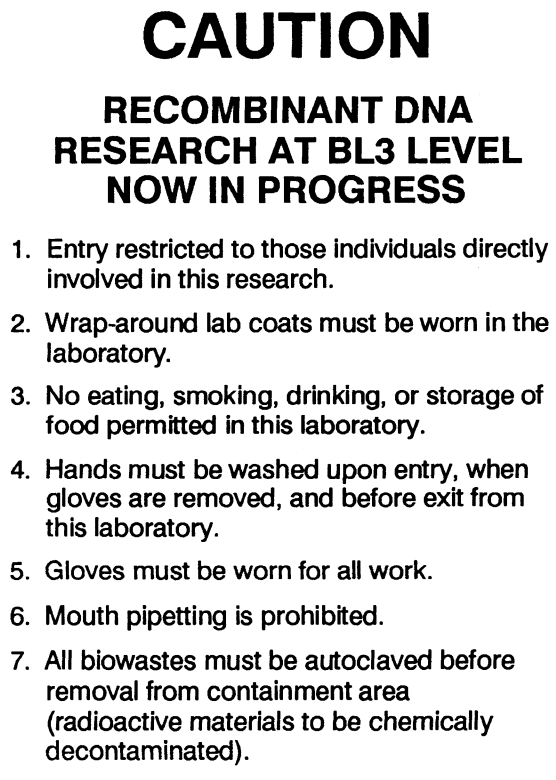

FIGURE 10.6 Example of a warning sign that should be posted outside the facility when BL3 experiments are in progress.