DESIGN GUIDELINE FOR BIOSAFETY LABORATORY CONSTRUCTION

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ABSTRACT : The case of laboratory-acquired SARS Corona virus infection in Taiwan has revealed a number of weaknesses in management, construction, and oversight of laboratories. Also, with the increased demands for bio-safety laboratory, there is an urgent need to develop a uniform and comprehensive guidance for architects and construction engineers in the preparation of design and construction. This research investigates the key elements for designers, engineers, and potential owners in biosafety laboratory design and construction. It defines key elements and determines major relationships and standards that should be adhered to when developing site layout. In addition to layout planning and design guidance of biosafety laboratory, this research also interviews the perspective of architects and survey the state-of-the-art technology in Taiwan. It represents the portraits by site investigation. The purpose of the research is to provide guideline of design and avoid potential future conflict to ensure the critical continuity of functions.

Key words : biosafety laboratory, BSL-3, BSL-4, design guidance

1. INTRODUCTION

After passing through such a disturbing time in 2003, the term "SARS" (severe acute respiratory syndrome) will remain an unforgettable acronym for most Taiwan people. Infectious SARS virus must be conducted in BSL-3 to provide researchers a safety working space. However, Focusing on problems occurring in the anti-SARS period, the government lack in experience and facilities to protect people. Problems exposed during the SARS period show that investment in the public health system is far from enough. Therefore, with the increased demands for bio-safety laboratory, there is an urgent need to develop a uniform and comprehensive guidance for architects and construction engineers in the preparation of design and construction.

1.1 Scope

BSL refers to a laboratory which, in terms of its structure, facilities, operation procedures and equipment, could prevent its staff from attack when experimenting on objects containing microbes and toxins causing diseases, as well as prevent the environment from being polluted. According to the harm of microbes and their toxins, such laboratories are divided into 4 levels, the 4th level being the highest, and related regulations request that research on infectious SARS virus must be conducted in BSL-3. Table 1 presents the relation of BSL to laboratory type, practices, and equipment.

Table 1. Relation of BSL to laboratory type, practices, and equipment [1]

Biosafety Level	Laboratory Type	Laboratory Practices	Safety equipment
BSL 1	Basic teaching, research	GMT	None; open bench work
BSL 2	Primary health services; diagnostic services, research	GMT plus protective clothing, biohazard sign	Open bench plus BSC for potential aerosols
BSL 3	Special diagnostic services, research	As Level 2 plus special clothing, controlled access, directional airflow	BSC and/or other primary devices for all activities
BSL 4	Dangerous pathogen units	As level 3 plus airlock entry, shower exit, special waste disposal	Class III BSC, or positive pressure suits in conjunction with class II BSCs, double-ended autoclave (through the wall), filtered air

According to laboratory type, if particular experiments require the generation of high-concentration aerosols, then Biosafety Level 3 and 4 may be more appropriate to provide the necessary degree of safety, since it ensures superior containment of aerosols in the laboratory workplace. This research will focus on the design and construction guidance of BSL-3 and BSL-4.

1.2 Problem Statement

A large NIH-sponsored infectious disease research agenda is unfolding at a cost of $2 billion per year. Currently there are too few researchers and too few biosafety-designed research facilities to support this effort. [2] Constructing even a small scale BSL-3 or BSL-4 project can be a difficult undertaking. Three potential problems loom on the horizon: the shortage of qualified design firms and contractors, proper maintenance of BSL facilities, and a shortage of trained personnel.

1. **Qualified Consultants**: Few contractors and designers have the experience to properly design biosafety facilities. Equally important to issues of design experience is the experience of the owners. Key staff with biosafety knowledge must be present and active in the planning process.
2. **Proper Maintenance**：The second looming problem is the proper maintenance of biosafety facilities. Such maintenance is very complex, expensive, and human-resource intensive. Emplo-yeeillness, poor scientific results, the loss of research time and dollars, and losing the ability to continue research are all consequences of impro-perly maintained BSL facilities.
3. **Properly Trained Staff**：The third looming problem is the need for adequate training of users and maintenance technicians in addition to quality design and construction. Training requires time, and it is an important point to note that there is a general shortage of trained people, as well as a lack of good training courses.

Maintaining biosafety facilities is an integral component to facility design. Many decisions made during the design stage have long-term implications for maintenance. As potential owners realize their opportunities and as facility planners, programmers, and designers become engaged in helping develop biosafety facilities (large or small scale), it is highly effective to integrate all components (management, operations, science programs, design, the public, engineering systems, security, safety, maintenance, funding, etc.) to successfully and properly carry out these projects.

1.3. Research Methodology

According to above reasons, this research reviews related literature and regulation and investigates the state-of-the-art technology in BLS-3 and BLS-4 projects. This research interviews the perspective of architects and analyses critical elements in design and construction phases.

2. BIOSAFETY LEVEL REQUIREMENTS

Although the focus of this document is BSL-3 and BSL-4, a comparison of all four biocontainment levels is helpful. Each level represents a different combination of laboratory practices, safety equipment, and laboratory facilities appropriate for increasing levels of protection. The levels represent a hierarchy, with all practices and procedures delineated at the lower levels carried forward to the next higher level. [3]

Table 2 illustrates the requirements of each biosafety level.

Table 2. Summary of biosafety level requirements [1]

	Biosafety Level			
	1	2	3	4
Isolation of laboratory	No	No	Yes	Yes
Room sealable for decontamination	No	No	Yes	Yes
Ventilation:				
- inward airflow	No	Desirable	Yes	Yes
-controlled ventilating system	No	Desirable	Yes	Yes
- HEPA-filtered air exhaust	No	No	Yes /No	Yes
Double-door entry	No	No	Yes	Yes
Airlock	No	No	No	Yes
Airlock with shower	No	No	No	Yes
Anteroom	No	No	Yes	-
Anteroom with shower	No	No	Yes / No	No
Effluent treatment	No	No	Yes / No	Yes
Autoclave:				
- on site	No	Desirable	Yes	Yes
- in laboratory room	No	No	Desirable	Yes
- double-ended	No	No	Desirable	Yes
Biological safety cabinets	No	Desirable	Yes	Yes
Personnel safety monitoring capability	No	No	Desirable	Yes

2.1 Characteristics of BSL-3 Facilities

The features that distinguish a BSL-3 laboratory from lower level (BSL-1 and BSL-2) microbiological labs are [3]:

1. Provisions for access control
2. A specialized ventilation system ensuring directional airflow
3. Use of biosafety cabinets or fume hoods for all laboratory activities

A BSL-3 laboratory may be a single lab, a suite of labs or an entire building. The primary objective of this type of facility is to provide the best possible physical containment of hazardous microorganisms or biological agents. All laboratory manipulations should be performed in a biosafety cabinet (BSC) or other enclosed equipment. The biosafety cabinet is relied upon as the primary device in BSL-3 laboratories for protecting products, personnel or the environment.

General exhaust air from the laboratory is often treated with High Efficiency Particulate Air (HEPA) filters before it is exhausted outdoors. A dedicated exhaust system may be required, depending on the class/type of biosafety cabinet used. One other functional aspect of a BSL-3 laboratory is the need for gaseous decontamination, essentially requiring a "tight" space. Penetrations must be capable of being sealed for fumigation purposes.

Several authorities publish guidelines for the design and operation of BSL-3 laboratories, primarily the National Institutes of Health's (NIH) Biosafety in Biomedical and Microbiological Laboratories (BMBL), the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), and Health Canada's Laboratory Biosafety Guidelines.

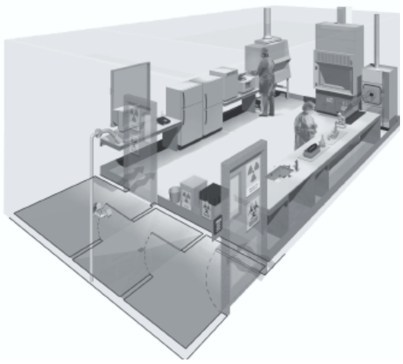

Figure 1. A Typical Biosafety Level 3 Laboratory [1]

2.2 Characteristics of BSL-4 Facilities

Referred to "Laboratory biosafety manual" published by World Health Organization, Biosafety Level 4 with the addition of the following.

1. **Primary containment** : An efficient primary containment system must be in place.
2. **Controlled access**: The maximum containment laboratory – Biosafety Level 4 must be located in a separate building or in a clearly delineated zone within a secure building. Entry and exit of personnel and supplies must be through an airlock or pass-through system.
3. **Controlled air system**: Negative pressure must be maintained in the facility. Both supply and exhaust air must be HEPA-filtered.
4. **Decontamination of effluents**: All effluents from the suit area, decontamination chamber, decontamination shower, or Class III biological safety cabinet must be decontaminated before final discharge. Heat treatment is the preferred method.
5. **Sterilization of waste and materials**: A double-door, pass-through autoclave must be available in the laboratory area.
6. **Airlock** entry ports for specimens, materials and animals must be provided.
7. **Emergency power** and dedicated power supply line must be provided.
8. **Containment drain** must be installed.

3. KEY ELEMENTS IN DESIGN AND CONSTRUCTION

The primary objective is to design a safe, accessible environment for laboratory personnel to conduct their work. A secondary objective is to allow for the maximum flexibility for safe research use. The research lists below elements in design and construction required for new and remodeled laboratories.

3.1 Flooring

The floor must be non-pervious, one piece, and with covings to the wall. This can be achieved by use of glue, heat welded vinyl flooring, epoxy coated concrete slab, etc. Floors in storage areas for corrosive liquids shall be of liquid tight construction.

Figure 2. Floors with welded seams

3.2 Door

The doors should be self-closing and locking, and open inward. Such self-closing doors are to be able to be opened with a minimum of effort as to allow access and egress for physically challenged individuals. It's solid construction, including the frame, and has opening which allow passage of large equipment. In addition, it is recommend the doorframe connection to the wall.

3.3 Wall

Penetrations for electrical, plumbing, and other considerations must be completely and permanently sealed. Wall surfaces shall be free from cracks, unsealed penetrations, and imperfect junctions with ceiling and floors. Walls should be painted with washable, hard non-porous paints.

Figure 3. Washable and easily cleaned surface and perfect junctions with ceiling

3.4 Windows

BSL-3 and BSL-4 laboratories should be designed without windows. However, laboratory windows, where present, shall be designed not to open. All interior windowsills shall be sloped, and the seams around the windows shall be sealed.

3.5 Ceilings

Gypsum board with epoxy paint ceilings, equipped with access panels, will be provided in glassware washing and autoclave rooms, where the potential for a high moisture level exists. [3] Access panels shall be fitted with gaskets that seal the door when closed and also the flange around the panel lip where it meets the ceiling. Open ceilings are acceptable provided minimal ducting and piping are present and all exposed surfaces are smooth and cleanable. In new construction, all access to critical mechanical equipment (ventilation ducts, fans, piping, etc.) shall be provided outside the containment facility.

Figure 4. Gypsum board with epoxy paint ceiling

Figure 5. Mechanical equipment above the ceiling

3.6 Plumbing

All penetrations are perpendicular to the surface and shall be caulked to be gas tight. All pipes into the BSL3 are secured to prevent movement. Provide fixtures resistant to corrosion of bleach and other disinfectants. Space and connections shall be provided so CO_2 and other specialty gases are stored outside. Back-flow prevention shall be provided on all faucets (including industrial water). All pipes shall be properly identified by use of labels and tags. Lab waste water lines shall be separate from domestic sewage, and a sampling point shall be installed in an easily accessible location outside the building. [5]

Figure 6. Pipes with clear color and tags

3.7 A sink and eyewash

A sink for hand-washing is to be located near the exit door in each BSL-3 laboratory (not in the airlock). Sink faucets shall be foot, elbow, or automatically operated. A combination eyewash/douse shower unit shall be located in near proximity to the potential exposure.

Figure 7. Eyewash equipment

3.8 Air balance and HVAC system

Air pressure in laboratories should be negative in relation to the corridor or adjacent non-laboratory areas. Potentially harmful aerosols can escape from the containment of the laboratory room unless the room air pressure is negative to adjacent non-laboratory areas. As a general rule, air should flow from low hazard to high hazard areas.

No recirculation of effluent (exhaust) air shall occur, that means 100% of the air shall be exhausted to the outside). Supply and exhaust dampers shall be gas-tight design and closable from outside the facility to facilitate decontamination. A ventilation system failure alarm shall annunciate in the laboratory and connected with the facility's alarms group or security. The air distribution system shall not create drafts at the face of any BSC. The BSL-3 and BSL-3 lab shall not become positively pressured if the exhaust system fails. Whenever possible, electrically interlock the supply and exhaust fans. [6]

HEPA filters, if provided on the exhaust system, shall be either "bag-in, bag-out" or capable of isolation (by gas-tight damper) to accommodate gas decontamination. Provisions shall be made to replace gas-decontaminated filters after decontamination when the decontaminant is incompatible with HEPA filter media (e.g. aqueous solutions that will weaken filter media or substances that will corrode or degrade the filter media).

A magnetic gauge or other pressure-monitoring device shall be installed to measure pressure drop across all HEPA filters. The magnetic gauges or pressure-monitoring devices shall be readable from outside the BSL3 facility.

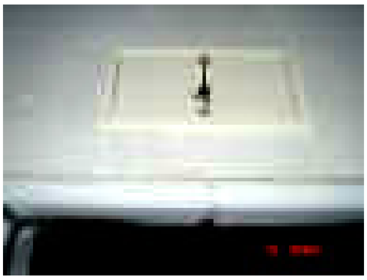

Figure 8. Pressure-monitoring device

3.9 Biological safety cabinets (BSCs)

BSCs are safety devices used for primary containment of biohazardous materials. These units are uniquely different from other types of laboratory hoods, and installation involves specific design consideration. BSCs are classified as Class I, II, or III, although Class I cabinets are no longer being manufactured on a regular basis. [7] The design of the HVAC systems shall allow for the maximum exhaust capacity for all BSCs, which may be required in the facility. Class III BSCs are totally enclosed glove boxes primarily used in BSL-4 laboratories, but they may also be used for work with hazardous chemicals.

Biological safety cabinets (BSCs) must be located away from doors. Biosafety cabinet should not be installed directly opposite of another biosafety cabinet if spatial considerations allow otherwise. A biosafety cabinet should not be installed directly under air supply inlets. Exhaust from an autoclave may contain heat and moisture that will blow into the ace of the cabinet. This will cause air turbulence in the cabinet and adversely affect the performance of the unit. There is also an increase of potential contamination within the cabinet if the autoclave is not functioning properly since the steam may contain spores or aerosols. [6]

4. CONCLUSIONS

This research interviews related experts who are well experience in design and construction of biosafety laboratory. Then summarize the state-of-the-art problems, including few qualified consultants, less proper maintenance, and few trained staff. Training requires time, but many decision-makings in design stage would affect long-term maintenance.

In order to provide laboratory personnel a safe and accessible environment to conduct their work and develop biomedical technology, the research lists nine key elements in design and construction required for new and remodeled laboratories. The nine elements include: the design and construction of flooring, door, wall, windows, ceiling, sink and eyewash, plumbing, air balance and HVAC system, and Biological safety cabinets (BSCs). The description with auxiliary photos assists designers, engineers, and potential owners to comprehend the real situation in design and construction stage of biosafety laboratory.

The research devotes to providing guideline of design and construction and avoids potential future conflict to ensure the critical continuity of functions.

REFERENCES

[1] *Laboratory biosafety manual*, third edition, World Health Organization, 2004.

[2] *Designing, Building and Maintaining Safe BSL Labs,* Trendline Inc., 2004.

[3] *NIH Design Policy and Guidelines*, Office of Research Facilities, 2003

[4] *BSL-3 Laboratory Design Resource*, Phoenix Controls Corporation, 2003.

[5] *General Requirements for Standard Laboratory*, EH&S Design Guide, Version 2.0.

[6] *Biosafety Level 2 Laboratories*, EH&S Design Guide, Version 2.0

[7] *Environment Health & Safety Laboratory Safety Design Guide*, University of California, 2002