BUILDING OPERATING management

Lab Design: High Risk, High Reward

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August 2008

What is a BSL Lab?

BSL labs conduct a wide range of research geared to elucidating, finding treatments for and preventing infectious disease. The nature of the research entails significant risks, which must be addressed in the design and operation of the labs, but successful projects can bring enormous rewards. Among the kinds of work occurring in BSL labs:

- Basic sciences researchers study the fundamental aspects of infectious agents.
- Diagnostic development organizations produce readily deployable, rapid-response diagnostic tools.
- Drug discovery firms evaluate the potential of therapeutics as antibiotics and vaccines for treating and preventing infectious diseases.
- Analytical screening organizations develop tools for rapid screening and identification of chemical, biological, radiological, nuclear and explosives (CBRNE) threats.

Repositories and resource centers maintain agent cultures, searching for disease biomarkers and working to improve methods for agent characterization.

The Challenges of BSL Lab Design

In an economy where scientific discoveries and medical breakthroughs play a prominent role, research laboratory facilities are evolving by the day. A good example is the growing number of Biosafety Level (BSL 1-4) facilities. These labs often involve the study of infectious microorganisms — critical to medical breakthroughs. These facilities vary in size, scope and complexity — by the level of containment protection required for personnel, the environment and communities.

More BSL environments are springing up today as more commercial organizations, academic centers and federal agencies realize the immense research value they can deliver. The National Institutes of Health (NIH) is a prime example. The National Institute of Allergy and Infectious Diseases, part of the NIH, devotes one-third of its annual budget to the study of emerging infectious diseases and biodefense.

Diverse skills are necessary to safely and effectively manage, operate and maintain all these environments. High containment and maximum containment facilities — BSL 3

and BSL 4 respectively — demand more specialized practices, procedures, safety equipment and facility requirements. Facility executives play a critical role in ensuring the proper safeguards are put in place. They are part of the principal agent team responsible for ensuring asset and environmental protection.

From Blueprints to Opening Day

Few facilities require more careful planning than BSL 3 or 4 laboratories. Because of the inherent challenges presented, facility planners must adopt a no-nonsense approach to design and construction oversight and system testing.

Special attention should be paid to key details including location; environmental metrics; internal and external access controls; floors, walls, and ceiling design; heating, air conditioning, ventilation, and humidity controls; intake and exhaust filtration systems; specialized infrastructure support requirements; and emergency support components.

In most cases, normal design and construction methodologies fail to meet the stringent requirements needed to certify BSL 3 or 4 facilities. Certification includes a comprehensive evaluation of room integrity, clearly demonstrating its ability to hold pressure within the stated standard. Certification also validates that air handling systems can meet NSF/ANSI standards and that laboratory equipment services provide safe and effective support to the facility.

Certification and validation should be considered an ongoing process relevant to the overall success of the project. Each element should be tested for compliance in both a standalone and integrated mode. Designers consider the impact each component will have on the system as a whole. Even the addition of a small, simple piece of laboratory support equipment into a previously certified working environment may dramatically change the working conditions within that space.

Finally, prior to commissioning, facility executives must show that the building meets all design specifications and physical requirements for conducting Level 3 or 4 work. This is normally accomplished through a post-construction inspection and review of all drawings.

The Need for Reliable Power in the Lab

Many facilities can tolerate a brief loss of electricity and control. The level of risk posed by the downtime or degree of impact on operations typically determines the measures used to return power to a facility. For example, conventional facilities that can tolerate some downtime may be provided with an emergency generator on a manual or automatic transfer switch, or have no emergency power at all. Other facilities with critical life-safety systems or devices, where any interruption in power is intolerable, are likely to require a UPS. More critical facilities will probably have a combination of features, including an automatic transfer switch to emergency power generation and UPS devices.

The role of emergency and backup power supply systems in BSL 3 and 4 cannot be overstated. To ensure a high level of protection, every critical safety system or element directly supporting the lab — including equipment, ventilation, lighting and control systems — must remain online without interruption at all times. Most systems or devices

will be hooked up to UPS, supported by back-up generators, or both. Emergency generators should automatically engage when the main power source is lost.

In other facilities, emergency power is generally relegated to providing control over critical systems. It is intended only to provide adequate power to allow systems to be shut down or to remain running in a sustainment mode while personnel safely secure the work area and evacuate. Because the majority of systems will not have redundant emergency power systems, procedures should be implemented that address the possibility of the generator not activating. Alarms and evacuation plans should be designed to account for and protect personnel and the facility. Personnel should be aware of the risks associated with working in these environments. They should be fully and constantly trained on evacuation procedures and protocols.

Lab Exhaust Air Requirements

ne of the most critical features of any BSL 3 or 4 laboratory is the ventilation and air management system. It serves as a critical line of defense from environmental exposure to pathogens and hazardous materials commonly used in the facility. It is imperative to pay close attention to each system to minimize the risk associated with materials entering or escaping from the system.

Design strategies include:

- Use of 100 percent outside air
- Managed directional flow to ensure air always flows toward the highest area of containment
- Pressure monitoring
- Audible and visual alarms to alert personnel if a system fails
- Back-draft protection
- Supply and exhaust HEPA filtration using filter housings designed to withstand the pressures associated with the system.

Avoid forcing conventional and containment areas to share exhaust and filtration systems. Special attention should be paid to the method used to mount duct sensors downstream of exhaust HEPA filters. Whenever possible, it should avoid sharp angles; opt instead for smooth turns. Duct material should be strong enough to hold up to pressure variations without risk of collapse.

Supply ductwork that passes outside the containment area must be airtight and leak-tested using a reassure decay method. Additionally, filters and filter housings should be tested to ensure all elements are properly sealed and maintain system integrity under sustained operational pressures.

Other Lab Design Factors: Physical Barriers and the Envelope

In BSL 3 and 4 labs, containment areas are separated from “conventional” areas of a facility. Physical barriers include walls, ceilings and floors — elements that are often first to be drawn following the facility footprint and support structures. Even though the locations of the walls will often change by the time as-built drawings are provided, they are generally the first indication of what the facility will look like.

Physical barriers should be positioned to permit efficient movement of materials and personnel in and out of the higher containment areas. The equipment to be used in the facility should be identified before the location of physical barriers has been determined. This information can be used to provide for appropriate staging areas, air locks, decontamination procedures, door height/width and ceiling height, and to accommodate swing radius for mobile equipment.

Physical barriers should also be positioned so that mechanical devices can be easily serviced. To take a simple example, supportive autoclave controls, pumps and motors should be accessible by service personnel from outside the high containment environment, so that staff doesn't need to don personal protective equipment to service this machinery. Physical barriers should be constructed of durable, cleanable, impact- and chemical-resistant materials. Placing primary crash barriers along walls (such as sani-rails) at strategic heights and off-sets is a good idea.

Expansion and control joints should be appropriately sealed to prevent post-occupancy voids as a result of structural movement due to environmental changes and settling of the facility. The width of these joints should be minimized where possible. Depending on their size, various methods may be employed to seal them. Shallow control joints and construction cuts may be sealed using a stable, cleanable and elastic caulk product. Large, deep expansion joints should be provided, with backer rod material inserted at a depth to accommodate no less than two times the width of the joint prior to sealing with the caulk.

Sealing Ceilings and Windows

Floors, ceilings and windows should be sealed to meet the performance requirements of the facility.

Monolithic floors should be extended up the vertical wall surface by integrating the floor material as a cove base. Cove base-to-floor intersections should be a tooled radius. Penetrations in the floor require a smooth finish for cleaning and decontamination. Broadcast or troweled aggregate substrates with monolithic epoxy or urethane top-coats are generally good choices.

Because ceilings have relatively minimal load- or impact-bearing requirements, a smooth, sealable surface that can withstand cleaning and disinfection modalities is the main requirement. Gypsum board materials with epoxy painted top-coats generally perform well. Suspended ceilings such as small mylar coated or FRP panels are not recommended. Maintaining a seal between the multiple small panels is not practical.

Tooled, paintable caulk seams or other sealable solids at the wall and ceiling joints are best. Another option is sealed fiberglass overlay creating a radius at this joint, but it costs more without significantly improving performance.

Careful attention should be paid to the installation of ceilings where recessed lighting applications are planned. Large, rigid, stainless steel light fixture housings are best for ceilings that are flat. The rigid housings and thin gaskets will not form a tight seal against a ceiling with minor rolls due to uneven fastening. Unnecessary additional caulking would be required to fill the voids.

Windows in higher containment areas should be avoided. If that isn't possible, the windows should be inoperable. All window frames and seams must be sealed. Solid molded window frames with gasket material between the window and frame generally work best.

Meeting Standards, Controlling Costs

In an ideal world, all BSL programs would benefit from rigorous pre-planning routines and consider all aspects of engineering and operational planning during the early phases of facility design. However, many labs are constructed either in existing buildings or as an afterthought in new construction. Either way, the design must meet the rigorous standards required of a BSL facility. The key is to understand fully the scope of work to be accomplished — before work begins.

A crucial step is to assemble a design team representing engineering, operations and management. An experienced BSL design and development firm can serve as a mentor and provide construction oversight, helping to prevent costly mistakes to resolve conflicts between team members.

Key questions to be assessed include:

- What is the primary threat. "Threat" refers to the infectious agent or other material being studied in the lab, which poses a threat if it is not contained.
- Will its arrival at the facility be anticipated, as in a research facility, or unanticipated, as may be the case in a diagnostic or security laboratory?
- Is the threat limited to biological materials, or could it include chemical, radiological, nuclear or explosive substances?
- Does the design provide a cost-effective, yet reliable solution?
- Will staff training and qualifications complement the capabilities of the lab?
- Is the basic workflow fully understood by the design team?
- Will the mission and therefore the workflow change?

Answering these questions and understanding how each relates to the overall design process will help avoid shortfalls and keep development cost under control.

BSL 3 and 4 environments will continue to set the standard for research excellence. As a result, a growing number of organizations will be constructing BSL 3 and 4 labs, and a growing number of facility executives will be responsible for managing them. With a sound construction strategy, the highest level of safety can be provided for the facility, personnel and surrounding community — while preserving the high level of research excellence.

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