Understanding the Challenges of Design and Engineering for Biocontainment
Agenda

Introductions
Overview
Learning Objectives – Case Studies
Summary Conclusions
Introductions

• Registered FL Architect, B. Arch FL A&M University

• Leader in the development of active learning spaces for academic environments

• Lectured on academic learning environments at SCUP / American School and University / FEFPA
• Registered FL Architect, Masters, Clemson University

• Over 30 years in the design Academic and Private research facilities

• Designed over 20 academic sciences facilities

• BSL2-3 / vivarium design experience

Bob Thomas, AIA, NCARB, LEED BD+C
Science and Technology Market Sector Leader
LEO A DALY
Introductions

- Healthcare Sector Leader - Oversees multidisciplinary team of architects, engineers, planners, designers
- 36 years of experience - Small clinics to large Greenfield hospitals
- Previously worked at the Georgia Institute of Technology facilities
Today, the nation is facing a new challenge in safeguarding the public health from potential domestic or international terrorism involving the use of dangerous biological agents or toxins. Existing standards and practices may require adaptation to ensure protection from such hostile actions. In addition, recent federal regulations mandate increased security within the microbiological and biomedical community in order to protect biological pathogens and toxins from theft, loss, or misuse.
Design Thinking

Guiding Concepts:

• Type of research anticipated today and in the future

• The Inter-relationships of researchers, students, staff and community

• Functionality – teaching labs / research labs / both
Design Thinking

Guiding Concepts:

• Shared research spaces or proprietary research needs/shared equipment

• Utility requirements and grouping of infrastructure needs

• Biohazards / chemical control zones
Design Thinking

Guiding Concepts:

• Laboratory Modules

• Equipment planning /vibration control/heat mitigation
Principles of Biosafety

• Laboratory Practices and Technique
• Safety Equipment (Primary Barriers and Personal Protective Equipment)
• Facility Design and Construction (Secondary Barriers)
Design Thinking
Design Thinking

The Guidelines BMBL

CDC Biosafety Levels

- **BSL-4**: Microbes that pose a high-risk of aerosol transmission. Infections caused by these microbes are frequently fatal and without treatment or vaccines. Examples: Ebola, Smallpox.
- **BSL-3**: Microbes that can cause serious or potentially lethal disease through respiratory transmission. Examples: HIV, H1N1 Flu, Yersinia pestis (The Plague), Tuberculosis, SARS, Rabies, West Nile Virus, Rickettsia.
- **BSL-2**: Microbes that pose moderate potential hazard to personnel and the environment. Examples: Most Chlamydia, hepatitis A, B, and C, influenza A, typhoid fever, Salmonella, diphtheria, mumps, and measles.
- **BSL-1**: Microbes that are not known to cause disease in healthy adult humans, and of minimal potential hazard to laboratory personnel and the environment. Examples: salmonellosis, non-pathogenic enterococcus, and non-infectious bacteria.
Biosafety 1 Design Considerations

- Well-characterized agents not known to consistently cause disease healthy adults, and present minimal potential hazard to laboratory personnel and the environment.
- Laboratories should have doors for access control.
- Laboratories must have a sink for hand washing.
Biosafety 1 Design Considerations

- Bench tops must be impervious to water and resistant to heat, organic solvents, acids, alkalis, and other chemicals.
- Chairs used in laboratory work must be covered with a non-porous material that can be easily cleaned and decontaminated with appropriate disinfectant.
BSL-2 is suitable for work involving agents that pose moderate hazards to personnel and the environment. All requirements in BSL-1 need to be met, and in addition:

- Laboratory doors should be self-closing and have locks in accordance with the institutional policies.
- Laboratories must have a sink for hand washing. The sink may be manually, hands-free, or automatically operated. It should be located near the exit door.
Biosafety 2 Design Considerations

- The laboratory should be designed so that it can be easily cleaned and decontaminated.
- Operable windows are not recommended.
- BSCs must be installed so that fluctuations of the room air supply and exhaust do not interfere with proper operations.
- BSCs should be located away from doors, windows that can be opened, heavily traveled laboratory areas, and other possible airflow disruptions.
Biosafety 2 Design Considerations

• Vacuum lines should be protected with liquid disinfectant traps.

• An eyewash station must be readily available.

• There are no specific requirements for ventilation systems. However, negative pressure is recommended.

• HEPA filtered exhaust air from a Class II BSCs can be safely recirculated back into the laboratory environment.
BSL-3 is suitable for work involving Exotic agents that can cause serious or lethal disease. All requirements in BSL-2 need to be met, and in addition:

- Separated from unrestricted traffic flow – Double door airlock
- A clothing change room (anteroom) may be included in the passageway between the two self-closing doors.
- Negative Air Pressure environment
Design Thinking

Biosafety 3 Design Considerations

• Monolithic Floor systems / Sealed penetrations

• The laboratory exhaust air must not re-circulate to any other area of the building.

• The laboratory building exhaust air should be dispersed away from occupied areas or the exhaust air must be HEPA filtered.

• Waste decontaminating - autoclave
Biosafety 4 Design Considerations

Biosafety Level 4 is required for work with dangerous and exotic agents that pose a high individual risk of aerosol-transmitted laboratory infections and life-threatening disease that is frequently fatal, for which there are no vaccines or treatments, or a related agent with unknown risk of transmission. All requirements in BSL-3 need to be met, and in addition:

• Negative Air Pressure environment.

• Monolithic Floor systems / Sealed penetrations
Design Thinking

Biosafety 4 Design Considerations

- Remove and replace clothing / showers
- Generally separate facility where possible
- Clean and dirty corridors
- HEPA filtration – self starting emergency power
- Sealed walls, floors, and ceilings to facilitate fumigation and prohibit animal and insect intrusion.
Biosafety 4 Design Considerations

- Drains in the laboratory floor must be connected directly to the liquid waste decontamination system.
- Redundant supply fans are recommended.
- Redundant exhaust fans are required.
- Supply and exhaust fans must be interlocked to prevent positive pressurization of the laboratory.
Academic Sciences
Research Facilities - Biocontainment Unit
BSL-3 Conceptual Plan

Source: Guidelines for laboratory design; Health and Safety Consideration, Third Edition 2001
BSL-3 Conceptual Plan

Circulation

Source: Guidelines for laboratory design; Health and Safety Consideration, Third Edition 2001
BSL-3 Conceptual Plan

Material Flow

Source: Guidelines for laboratory design; Health and Safety Consideration, Third Edition 2001
BSL-3 Conceptual Plan

Air Pressure and Flow

Source: Guidelines for laboratory design; Health and Safety Consideration, Third Edition 2001
Academic Medicine
Patient Care -
Biocontainment Unit
• Since mid-2014 and the most recent outbreak of the Ebola Virus Disease (EVD), the containment of patients with serious diseases has been a hot topic.

• Although the threat of EVD is significantly reduced, and almost non-existent in the US, threats from infectious diseases remains very real.

Simulation image courtesy of Nebraska Medicine
The Global Infectious Disease Threat

- Infectious Diseases:
  - 1/4 to 1/3 of the deaths worldwide.
  - 20 reemerged since 1973 (*TB, malaria, cholera, diphtheria, pertussis, measles, ...*).
  - 30+ previously unknown identified since 1973 (*HIV, Ebola, hepatitis C, Nipah*).
  - Deaths in the United States have doubled to 170,000 annually.
  - *Influenza* now kills some 30,000 Americans annually.
  - Many infectious diseases originate outside US borders and are introduced by international travelers, immigrants, returning US military personnel, or imported animals and foodstuffs.
  - It’s the secondary cases that create the problems -- OUTBREAK

“It's not just an Ebola-isolated issue,” said Dr. Mark Jarrett, senior vice president and chief quality officer at North Shore-LIJ. In a global society, rare viruses are just a plane ride away”
Management of Infectious Patients

• All hospitals have private patient rooms (>10% of the total) designed as Airborne Infection Isolation Rooms (negative pressure).

• All hospitals have procedures and training to manage airborne-isolation and contact-isolation patients.

• But, some infectious agents exceed the norm...
Management of Infectious Patients

- The CDC has guidelines governing the design and operation of facilities storing, handling, and investigating infectious agents.

- Some agents, like Ebola and smallpox, require maximum containment and control.

- Hospitals that treat Ebola and similar infections must meet both the guidelines of the CDC and the guidelines for hospital design.
**CDC Biosafety Levels**

- **BSL-1**: Not known to consistently cause disease in healthy adult humans, and of minimal potential hazard to laboratory personnel and the environment. Examples: canine hepatitis, non-pathogenic Escherichia coli, and non-infectious bacteria.

- **BSL-2**: Moderate potential hazard to personnel and the environment. Includes bacteria and viruses that cause only mild disease to humans, or are difficult to contract via aerosol in a lab setting. Examples: Most Chlamydiae, hepatitis A, B, and C, influenza A, Lyme disease, Salmonella, mumps, and measles.

- **BSL-3**: Microbes that can be either indigenous or exotic, and they can cause serious or potentially lethal disease through respiratory transmission. Examples: HIV, H1N1 Flu, Yersinia pestis (The Plague), Tuberculosis, SARS, Rabies, West Nile Virus, Ricketts.

- **BSL-4**: Dangerous and exotic, posing a high risk of aerosol-transmitted infections. Infections caused by these microbes are frequently fatal and without treatment or vaccines. Examples: Ebola, Smallpox.

**High Risk Microbes**

**Low Risk Microbes**
Case Studies

Biocontainment Patient Care Unit
University of Nebraska Medical Center

Patient Isolation Ward
Ft. Detrick, MD
The Nebraska Medical Center
Biocontainment Patient Care Unit

Nebraska Medicine’s Goal:
Treat patients with serious communicable diseases

Infected with pathogens introduced by:
• Bioterrorist act
• Global infectious disease
• Laboratory accident
The Nebraska Medical Center
Biocontainment Patient Care Unit

- 4,100-SF facility
- Five patient rooms (originally 10 beds)
- First of its kind and nation’s largest to date
- Environmentally self contained

CONSTRUCTION COST: $695,000 (2004)
PROJECT BUDGET: $1,000,000 (2004)
The Nebraska Medical Center
Biocontainment Patient Care Unit

Operational Features:

- Constructed in 2004
- Renovations to a 1920’s patient ward
- Intended for airborne infections (SARS)
- First used for contact infections (EVD)
The Nebraska Medical Center Biocontainment Patient Care Unit

Design Features:
- Inter-locking Doors at Airlocks
- Dunk tank; Autoclave
- Dedicated HVAC
- 100% Redundancy of supply and exhaust
- Monitored air-pressure relationships
- Exhaust air – UV and HEPA
- Fully sealed environment
- Seamless; Scrubable
- Impact-resistant windows
Patient Isolation Ward
Ft. Detrick, MD
 Operational Features:

• Constructed in 2012
• Renovations to a 1950’s laboratory building
• Constructed as a BSL-4 Suit Lab
• Intended for the care of laboratory workers suspected of or having actually come in contact with a BSL-4 agent during work with a research subject
• Primarily used as a training facility for working in a BSL-4 environment
Patient Isolation Ward
Ft. Detrick, MD
Patient Isolation Ward
Ft. Detrick, MD
Biocontainment Patient Care Unit
University of Nebraska Medical Center

Patient Isolation Ward
Ft. Detrick, MD
Case Studies
Lessons Learned

- Ebola treatment produces a significant amount of **waste** -- soiled PPE, lab testing supplies, and linens. The waste produced in 24 hours of caring for an Ebola patient took 12 hours to sanitize, leading to bottlenecking at the autoclave. Therefore:
  - Storage space is needed for the staging of soiled items.
  - The number of Ebola patients is limited severely.
  - Redundant autoclaves would increase capacity and prevent the catastrophic risk of an autoclave breakdown.
Case Studies
Lessons Learned

• Ebola treatment requires frequent lab tests to test for presence of the disease. Therefore:
  • A point-of-care lab is preferred in the treatment of Ebola.

• The risk of life-threatening emergency in Ebola care is great, necessitating the ready availability of life-support supplies. Therefore:
  • A “clean” utility is needed on-site for the safe staging of emergency equipment.
Case Studies
Lessons Learned

• **Separation of clean and dirty** is essential; avoid areas of ambiguity between “clean” and “dirty,” including the vestibule area where incoming and outgoing staff intersect. Therefore:
  • A clear delineation between “clean” and “dirty” zones and circulation.

• A co-ed nursing staff, and the frequency of changing into PPE, creates the need for **privacy** in the changing area.
Case Studies
Lessons Learned

• A unit’s **design flexibility** should allow it to be used for other inpatient and training purposes during non-containment use. During the treatment of Ebola, some patient rooms may be used for other purposes, such as laboratory, clean storage, and dirty storage. In designing a new unit, the flexibility of spaces should be debated and additional infrastructure installed to support multiple uses.
Case Studies
Lessons Learned

- Adequate accommodations for the **Family** are essential for both family and patient.
  - Two-way CCTV to dedicated conference rooms.
  - Family interaction opportunity at the patient room?
  - Specific family sleep/living space.
- Specific space for **Security** personnel to operate from outside the unit should be designated if the unit is within a larger structure.
Case Studies
Lessons Learned

- **Location** of the Unit
  - Flow of staff, patients, and supplies into and out of the unit.
  - Flow of waste out of the unit.
  - Security of the area and access to it.
  - Ability to provide appropriate mechanical support.

- Local alarming of negative pressure system.

- **Cleanability** of surfaces, **durability** of materials, storage and maintenance of equipment.
Case Studies
Lessons Learned

• **Patient furniture** that is easily cleanable and holds up to the abrasiveness of cleaning materials.

• When the unit is locked down, no technicians are able to enter. This leaves nursing staff responsible for any **repairs**. Access to tools, and a place to keep them, is essential.

• **Decontamination of the transport devices** used to move new patients into and waste products out of the unit.
Case Studies
Lessons Learned

• **Practice, Practice, Practice.** Staff must be SO trained in *donning* of the suits, caring for patients while wearing the suits, and *doffing* the suits, that the procedures are second-nature and the occasions for mistakes are practically eliminated.

• The design and the operations are all about *containment.*
Nebraska Ebola Method: For Clinicians

https://www.unmc.edu/cce/neb_ebola.htm

Apple iTunes U

- General Information on Ebola
- Best Practices
- Personal Protective Equipment (PPE)
- Triage in ER & Clinics
- Patient Management
- Employee Exposure
- Laboratory
- Cleaning/Waste
- Transportation
Biocontainment is more than signage
A Theoretical Model: Combining BMBL Principles with Patient Care Guidelines
A Theoretical Model: Combining BMBL Principles with Patient Care Guidelines
Conclusions

• Sick people may make other people sick.
• All infectious agents should be contained.
• The type(s) of containment vary according to the “danger” of the agent.
• Infectious agents mutate.
• It seems that there is always a new superbug.
• Awareness is good; misinformation creates panic.
• The essence of biocontainment is containment.
• Support the Patient; Protect the Staff.
Discussion