

The APL Chemical and Biological Test and Evaluation Center

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The new Chemical and Biological Test and Evaluation Center at APL offers the ability to test and evaluate technologies and systems critical to the protection of buildings and facilities against chemical or biological attack. Such testing with representative challenge aerosols is important not only to the security of a building environment but also to the application of the same technologies to medical and public health venues. This article presents an overview of the facility and its capabilities.

INTRODUCTION

Since 1994, APL has been working to develop and support systems to counter the threat of chemical and biological attacks to U.S. military and civilian populations. A major focus of this effort has been the development of next-generation sensors such as the Biological Time-of-Flight Mass Spectrometer, Fluorometric Affinity Biosensor, Fast Gas Chromatography Mass Spectrometer, and imprinted polymers, and the advancement of novel aerosol detection and collection methods.

In addition to expanding sensor technology, APL recognizes the need for a systems engineering approach to chemical and biological threat reduction in building environments by developing strategies that can be applied to such environments to reduce the effectiveness of chemical and biological attacks. These strategies should incorporate complementary technologies such as high-performance filtration, damper controls, decontamination methods, neutralization, and specialized airflow controls to mitigate the release of a chemical or biological threat within a building.

Many of the standards currently applied to these tools, however, are oriented toward conventional heating, ventilation, and air conditioning (HVAC) systems and are therefore not adequate against chemical and biological attack. The design and implementation of effective building protection systems requires additional testing. To fulfill this need, APL has designed and built a laboratory test bed for testing and evaluating new technologies in a small-scale, highly dynamic, yet controllable environment.

BACKGROUND

Large facilities typically have several air handling systems that can interact in unpredictable fashions. Furthermore, different threat scenarios may require different concepts of operation and rules of engagement in terms of people, sensors, and air handling technologies. The need for a test bed to test and evaluate novel technologies in a controlled environment stems from APL's systems

engineering approach to problem solving: first understand and control all subsystem issues before tackling larger systems that may be prohibitively difficult to analyze.

Determining the performance of individual sensors and building protection strategies requires a flexible test bed capable of varying individual parameters found in the complex building environment. For example, in specific airflow configurations, the natural leakage rate between rooms in an office complex could significantly contribute to the spread of a contaminant. Without the ability to measure and adjust these parameters, test results could misrepresent real-world scenarios, thereby suggesting ineffective solutions or responses to biological or chemical agent releases.

Virtually no data exist on the performance of filters, dampers, neutralizers, and sensors against real biological substances under controlled conditions of temperature, pressure, humidity, and flow rate. To meet these challenges, APL designed the Chemical and Biological Test and Evaluation Center (CBTEC), a facility that provides laboratory space for evaluating and quantifying experimental results using real vegetative and spore-forming bacterial agent simulants and simulants representative of chemical warfare agents and toxic industrial compounds.

FACILITY OVERVIEW

The CBTEC (Fig. 1) is a 1700-ft² facility featuring a 4500-ft³ aerosol chamber that consists of a suite of three 140-ft² offices with an interconnecting hallway. A fully equipped Biosafety Level 2 (BSL-2)¹ laboratory surrounds the chamber and provides space for supporting microbiological and chemical test activities as well

as a secondary barrier to prevent the spread of aerosols disseminated in the chamber space. The facility is also used extensively as an isolated microbiology laboratory for analysis and characterization of background environmental samples in a variety of programs.

The center was designed to be large enough to provide adequate performance data on a variety of detection and mitigation systems, yet small enough to allow rapid test turnaround times and relatively low decontamination and maintenance requirements between test runs. The CBTEC offers a unique capability in terms of size and functionality to enable the testing and integration of a wide range of technologies.

Aerosol Chamber

At the heart of the CBTEC is its highly flexible aerosol chamber, which offers unique capabilities to disseminate and measure the propagation characteristics of a variety of chemical and biological agent simulants throughout a simulated office building environment. Each of the three rooms in the chamber is equipped with pressure sensors, temperature probes, observation windows, and multiple access ports that allow unimpeded access for generating and sampling aerosols. A waterproof floor and weatherproof outlets, phone jacks, and Ethernet ports allow testing of decontamination materials without requiring major renovations between experiments.

Heating, Ventilation, and Air Conditioning System

Perhaps the most useful test system attached to the facility is an extremely capable, self-contained, highly functional HVAC system (Fig. 2), which uses active controls, redundant flow paths, and sensor feedback to create a very flexible test bed.

The supply air system is fed by two parallel blowers. The primary blower provides flow rates for normal heating and air conditioning of the chamber space. For specific experiments, such as the use of an emergency exhaust system, a secondary blower with approximately twice the airflow of the first system can be activated, resulting in 3 times the normal flow rate. Air is fed into the chamber space via a single mixed supply duct equipped with a high-output steam humidifier allowing up to 90% relative humidity. In addition, the main supply duct has been configured with removable straight sections

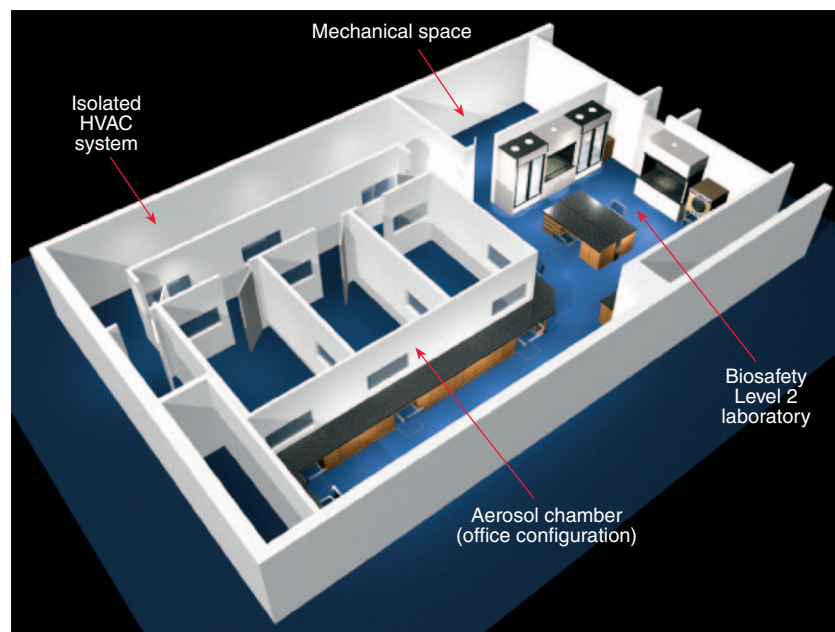


Figure 1. Layout of the Chemical and Biological Test and Evaluation Center.



Figure 2. The supply side of the HVAC system for the aerosol test bed in the CBTEC.

that can be replaced with in-duct aerosol or vapor mitigation technologies. The first section has two removable panels that allow experiments (sensors or sterilizing units, etc.) to be temporarily installed and tested.

The walls of each room extend from floor to ceiling, effectively isolating the rooms from one another. A dropped ceiling area above the rooms and hallways contains all of the HVAC supply and return ductwork. Also in this false ceiling area are variable dampers between the rooms to create leakage between spaces and to allow a plenum or ducted return configuration.

Finally, two independently controlled ceiling blowers in the plenum space over the two end rooms can, when activated, discharge room air to the outside through HEPA (high-efficiency particulate air) filters.

For the main airflow within each room, there are electronically controlled supply and return air dampers. By adjusting these dampers, the facility can be configured in either a duct-in/duct-out or duct-in/plenum-out configuration to represent one of two typical building airflow systems. For the supply air to the system, there are three independently controlled air inputs: outside air, plenum return air, and duct return air. The percentage of input air from each of these sources can be adjusted independently, using either 100% fresh or 100% return air or any combination thereof. For example, typical buildings may use an 80/20 mix during the winter and a 20/80 mix during the summer to conserve heating and cooling energy.

All supply air, whether return or fresh, is then passed through one or two selectable filter banks. Each bank

can accept a variety of filtration materials from standard 20% particulate removal filters up to HEPA and carbon bed filtration systems. This capability allows the operator to easily switch filter banks from a particular filtration technology as installed to a HEPA air wash between test runs by simply activating a damper control node.

The CBTEC also contains a variety of sensors that provide real-time feedback as to the state of the facility. Examples of sensors include those for humidity and temperature in each room, differential air pressure between the laboratory rooms and between the rooms and the hallway, supply air temperature, and outside air temperature. In addition, a low-temperature sensor in the air stream shuts the system down if, for any reason, the airflow temperature drops below freezing. The current is

monitored on all blower motors to sense motor failures or circuit breaker tripping.

Flexible Control System

Several commercial control systems were evaluated for the CBTEC, and the decision was made, based on overall commonality, flexibility, and expandability, to install a Siemens Apogee system. This system consists of a panel called the MBC (modular building controller), which resembles a large circuit breaker panel. Modules consisting of two to four analog or digital inputs or two to four analog or digital outputs are placed in the panel to control or monitor all system functions. This panel also includes a power supply and processor module, which connects to a local host PC.

The system is fully capable of stand-alone or computer-controlled operation. Downloaded programs can be run by the MBC without the PC being turned on or even attached to the system. However, if the PC is in communication with the MBC, independent control can be asserted over any of the system functions. If optional software is installed, this control can be asserted remotely from any location. In addition, the PC can graphically track and store any of the sensor or control parameters during experiments. Alarm values can also be set for any sensed or controlled parameters, and software is available to generate pager messages if any of these parameters exceed set limits.

Screen shots of the control system showing the status of the AHU1 (air handler unit 1) and HVAC systems are presented in Fig. 3. Any icon can be double-clicked to quickly bring up a control or status screen that shows

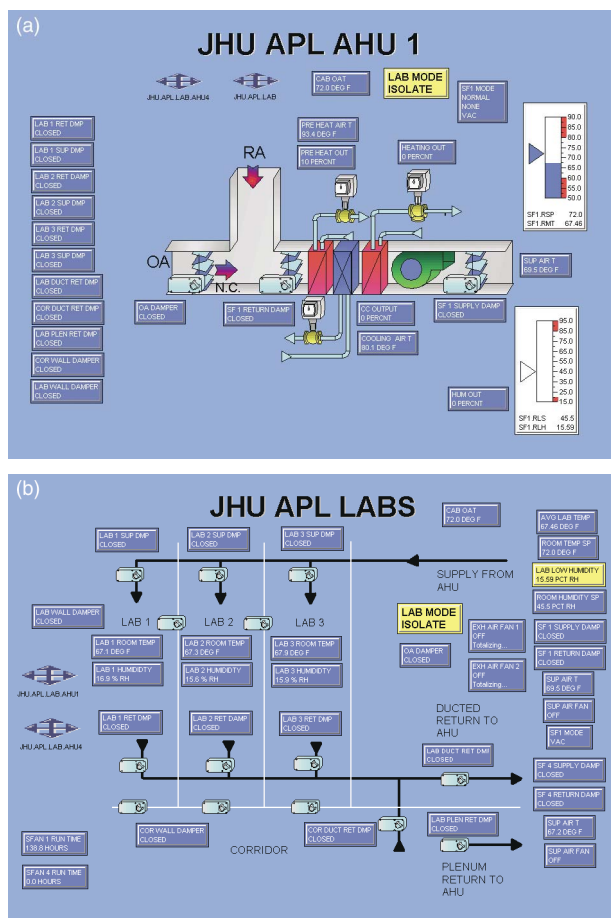


Figure 3. Control screen shots showing the status of the (a) CBTEC air handler unit (AHU) and (b) HVAC system.

detailed information on the sensor or actuator and allows program-independent control to be assumed.

The programs in the MBC processor system are “normal,” “clear,” and “isolate.” The normal mode functions as a regular time-programmable thermostat would, and maintains temperature and humidity in the laboratories at a preset point during working hours and at a different preset point during nonworking hours. The temperature and humidity in the laboratories are not maintained independently but as an average value across all rooms. The clear mode air handler operates both blower units using outside air and also operates both ceiling fan units so that the laboratories are evacuated at the maximum possible rate with fresh air. Finally, the isolate mode shuts off all blowers and closes all dampers so that there is no air communicating between any spaces. Additional operating modes will be programmed as needed for future experiments.

Biological Laboratory

The biology area of the CBTEC houses several sophisticated analytical instruments and equipment common to BSL-2 laboratories in which standard

microbiological and molecular biology techniques are performed. Figure 4 is a photograph of the facility showing one of the aerosol facility observation windows.

Typically, when the laboratory receives samples to be analyzed, they are processed in one of two biological safety cabinets called “hoods.” The Class II hoods use a unique airflow management system that creates a vertical flow of clean air across the work surfaces, preventing the spread of biological or chemical contaminants from the hood to the laboratory and vice versa. HEPA filters are used for contamination control of both exhaust and supply air. In the case of the chemical hood, air is exhausted outside the laboratory environment through a vent hood.

After processing, bacteria in both test and environmental aerosols are counted to determine the number of colony-forming units per milliliter by plating an aliquot of the sample on growth media plates via the Interscience Spiral Plater model DS Plus. This microprocessor-controlled dispenser enables the direct plating of bacterial suspensions ranging in concentrations from several up to 500,000 or more colonies per milliliter.² The plates are then incubated for a predetermined amount of time in one of three incubators: two air-jacketed, manual flow, CO₂ incubators that have flowmeters, allowing CO₂ concentrations to be adjusted from 0 to 20%, and an orbital incubator shaker for culturing samples in liquid media up to 6 L in volume.

After the incubation period, colonies on the plates can be counted with a single click of a button via the Spiral Biotech QCount colony counting system. This system complies with FDA 21 CFR (Code of Federal Regulations) Part 11 (Electronic Records; Electronic Signatures) and Part 58 (Good Laboratory Practice) and saves each plate image in a database.³

Established protocols can subsequently be followed for using a water bath and microcentrifuge to extract DNA from the colonies. The DNA is then typically amplified using polymerase chain reaction instrumentation and sent to a sequencing facility for genomic identification. Once the DNA sequence has been ascertained, it can be evaluated to determine the identity of the organism.

Protein can also be analyzed in the laboratory using a spectrophotometer or spectrofluorometer. The spectrofluorometer is a sophisticated analytical instrument that employs computer control and excitation and emission monochromators to measure and record the fluorescence spectra of a given sample. The fluorescence intensity and spectra are then used to quantitatively determine protein concentration.

For aerosol experimentation using abiotic particles such as polystyrene latex beads, an aliquot of the sample can be examined and quantified under a fluorescent light source or a polarizing and materials science microscope. Alternatively, the sample can be quantified in a Coulter counter.



Figure 4. Biosafety Level 2 portion of the CBTEC. An observation window looking into the aerosol chamber section of the facility is shown in the center of the photograph.

After all of the various analyses are completed, aliquots of the original samples can be archived in a -80°F freezer while the original samples and the growth media plates are stored in a standard chromatography refrigerator. All biowaste is sterilized in an electric steam sterilizer before disposal.

In the 12 months since commissioning, the biology area of the CBTEC has supported numerous background characterization programs in addition to ongoing research into mail security, matrix-assisted laser desorption/ionization mass spectrometry, and bio-aerosol detection programs. The center is regularly monitored for bacterial contamination levels, and standard operating procedures are in place that provide adequate decontamination if background contaminant levels are exceedingly high.

RESEARCH DIRECTIONS

Systems Engineering

Before the CBTEC was constructed, APL was pursuing detailed research on both internally and externally funded programs toward threat definition, mitigation response determination, and the integration of advanced technologies within the existing facility infrastructure. A successful approach at minimizing the effects of chemical and biological attacks on infrastructure will likely incorporate both active and passive mitigation technologies. In addition, damage can be minimized through a systems engineering approach, incorporating both active and passive filtration, real-time and short-time delay detection technologies, forensic analysis capabilities, and effective and rapid

decontamination systems for building restoration after an attack.

Internally funded activities toward this end have included the integration of detection and monitoring technologies into the existing building infrastructure. This integration has demonstrated the ability to modify existing structures with some active control or monitoring equipment without major renovations. Specifically, APL has demonstrated the ability to transmit chemical and aerosol particulate sensor data to a centralized command post via Ethernet and commercially available power line communications systems. Both solutions are effective on a local scale and could be used in conjunction with wireless or other fiber-based communications systems, bypassing the need for substantial building modifications.

Modeling and Validation

The Laboratory is also pursuing limited agent propagation modeling that will compare modeling results with actual experimental agent concentration data. Modeling input parameters generally include particulate size, fan flow models, damper actuation characteristics, leakage rates, door position, temperature and humidity effects, and line losses, among others.

Past modeling results suggest that agent propagation models can be drastically changed based on the boundary conditions and initial conditions used in problem definition. In addition, there are discussions about the validity of many zonal models compared with computational fluid dynamic (CFD) models, i.e., which system produces more accurate results. (For an example of CFD modeling related to bio-agent propagation, see the article by Scorpio et al., this issue.)

APL—through validation experiments run in the CBTEC—hopes to address some of the outstanding issues relating to the validity and usefulness of modeling results for chemical and biological agent propagation in building environments.

CONCLUSION

Effective chemical and biological threat reduction in a building environment requires intelligent interoperability between chemical and biological sensors, HVAC system components, mitigation technologies, and other basic building operations. The ability to test system integration technologies prior to installation in operational facilities will greatly reduce risk as well as test and evaluation time.

The CBTEC was designed primarily as a highly flexible test bed for evaluating these system integration and sensor-specific technologies. Secondary to this, the facility provides adequate laboratory space for a broad range of chemical and biological analysis techniques in support of a variety of background characterization activities. The CBTEC and its capabilities have already been used to further the development of sensors and sensor-system technologies for

the reduction of chemical and biological threats to critical infrastructure.

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