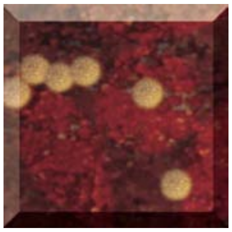

Countermeasures Against Chemical/Biological Attacks in the Built Environment

Harvey W. Ko

It is well known that buildings and facilities are susceptible to attack with chemical and biological agents. Builders, architects, security specialists, and technologists are engaged in discussions on what systems and practices are required to form countermeasures against such attacks. A facility in which sensors have detected a threat and active mechanical system control occurs to adapt to the threat is often called the "immune building." This article provides a framework for the assembly of concepts of operation, rules of engagement, and systems engineering necessary to adequately frame a cost-performance envelope for developing a countermeasures architecture.

INTRODUCTION

In October 2001, the death of a newspaper worker in Florida from inhalation anthrax began a series of tragic events that raised the public's concern about the use of biological agents to attack the workplace. Later that month, more letters containing anthrax were found in New York City and Washington, DC, that also caused indoor morbidity. The unexplained inhalation anthrax deaths of two people not connected to the scenes of the anthrax letter attacks showed the dangers of exposure to secondary contamination. These letter attacks resulted in 5 deaths and affected more than 20 other people in 2001. Concerns about wider contamination and morbidity from anthrax letters (see the article by Scorpio et al., this issue) have led to hundreds of millions of dollars in remediation of the affected facilities.

Anthrax is not communicable from one person to another, but the fear exists for attacks with highly contagious agents such as smallpox. In our mobile American society, biological terrorism calculations estimate that the exposure of 24 unknowing victims in 1 state could cause the disease to spread to 25 states and affect 3 million people in 2 months. An epidemic spread originating from a single indoor source is not inconceivable, since in 1970 smallpox viral particles from a single patient in a hospital in Meschede, Germany, accidentally infected 74 others through viral particle transport within and outside the building. Accidental indoor illness and morbidity from low concentrations of biological pathogens is not uncommon as health facility nosocomial infections affect thousands each year. However, the intentional use of biological warfare agents to attack the built environment is a relatively new concern of immense proportion.

The use of chemical agents to attack the built environment has also been demonstrated. In 1994, the militant Aum Shinriyko cult used sarin nerve gas to attack victims living in apartments in Matsumoto, Japan. A spray device, located on a nearby parking lot, was able to dispense the deadly gas onto several buildings, resulting in 500 victims and 7 indoor deaths. This attack was followed by the Aum Shinriyko sarin attack inside the Tokyo subway in 1995. In 2002, the Russians demonstrated to the world how a gas inserted into a building could be lethal. They used fetanyl citrate, an easily accessible anesthetic, which immobilized and killed 115 people to end the Moscow theater hostage crisis.

In recent years, several government agencies have published guidelines for safeguarding buildings against chemical and biological attacks. These guidelines summarize ways to deny building and HVAC (heating, ventilation, air conditioning)[1] access to potential perpetrators and describe air filtration options.[2] This article goes beyond the use of building mechanical strategies to demonstrate the value of a systems engineering approach that employs attack scenarios, performance criteria, sensor technologies, and concepts of operation (CONOPS) to arrive at an overarching countermeasures architecture. These ideas stem from a well-attended discussion of the "immune building" concept in January 2000 and a series of briefs to The Infrastructure Security Partnership (TISP), the Society of American Military Engineers (SAME), and the Federal Facilities Council.

COMPONENTS OF A COUNTERMEASURES ARCHITECTURE

Illustrative Attack Scenarios

In this section we present three scenarios. A calculation of air contamination flow resulting from the hypothetical release of a chemical agent is shown in Figs. 1 and 2. Here, the APL version of a modified National Institute of Standards and Technology (NIST) CONTAM96 HVAC model is used.[3] The modification adds subzones to the CONTAM96 model, adds molecular diffusion to the flow, and incorporates a real-time graphic user interface.

The floor plan in Fig. 1 (Scenario I) contains 12 offices, 6 (each 36 m^2) on either side of a hallway (96 m^2). At the north end of the hall (top of floor plan) is a supply inlet to the HVAC, into which a terrorist chemical agent is inserted at time t_0 at a rate of 5 mg/s. The agent concentration is 0.1 kg agent/kg air. In this scenario, no corrective action is taken. At t_0 + 5 min, the agent has moved down the hallway and is spreading into offices via HVAC supply ducts in each office. The center of the hallway is contaminated above the lethal level. At t_0 + 10 min, the hallway is completely contaminated beyond the lethal concentration, and the offices have reached the acute concentration. At t_0 + 20 min, the entire floor is above the lethal level.

In Fig. 2 (Scenario III), sensors have detected the threat and active HVAC control takes place. At t_0 + 5 min, 100% clean air is introduced at twice the normal flow rate, all windows (or clean supply vents) are opened, the north end main supply inlet is shut, the south end main return vent is shut, and an exhaust fan at the north end is turned on. The result is an immediate dilution of agent contamination. At t_0 + 20 min, the agent concentration is reduced to less than the lethal concentration in the hall, and this is all accomplished as the terrorist agent is still disseminating.

Figure 3 summarizes the benefit of active HVAC control. Figure 3a plots the instantaneous threat concentration and the threat dose over time. (This is an upper bound for the true human dose, which depends on breathing tidal volume.) The upper curve is Scenario I,

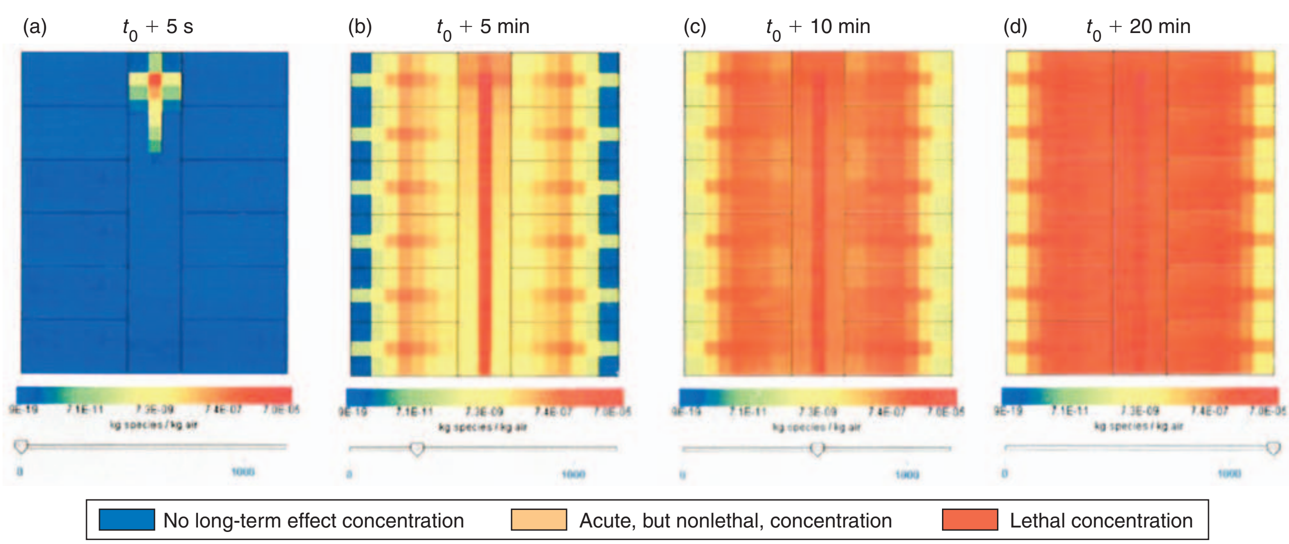

Figure 1. Contamination modeling of a constant release of 5 mg/s into the HVAC supply with all doors open and 100% recirculation of indoor air: (a) contaminant spreads from the source, (b) contaminant moves down the hallway and spreads into offices via supply ducts, (c) the hallway is completely contaminated and offices are contaminated between the supply duct openings and hallway, and (d) the contaminant continues to spread in offices, with increased concentrations everywhere.

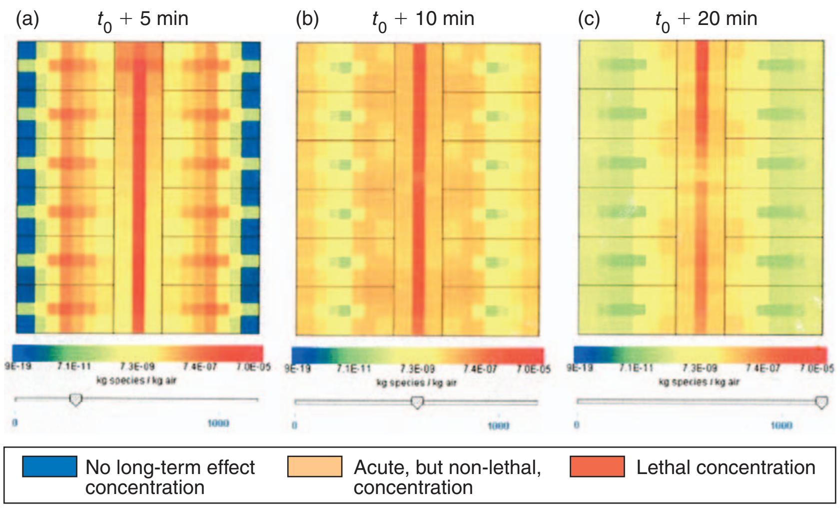

Figure 2. Contamination modeling with 100% clean air introduced at twice the normal flow rate and with the HVAC supply shut: (a) onset of corrective action, (b) clearing is evident, especially in offices, and (c) offices are almost completely clear.

where the threat is disseminated and no action is taken. The middle curve is Scenario II, where fresh air is introduced but no supply or return vents are manipulated. In Scenario III (the lower curve), both fresh air and HVAC ventilation controls take place and the action is now initiated at t_0 + 1 min. The benefit (reduced contamination) is obvious. (We note that t_0 + 1 min was taken arbitrarily for initiation of an active response.)

A building protection strategy can result from a build-test-build program to explore the following benefits through modeling and simulation as well as test-bed experiments:

- Intelligent placement of filters, sensors, and neutralization apparatus
- Swift contamination reduction through manipulation of HVAC controls triggered by sensors
- Quick remediation of contaminated air by the rapid insertion of clean air and the intelligent exhaust of contaminated air
- Continuous purification of air by biological and chemical neutralization methods
- Surge methods of clean air insertion, bad air extraction, and neutralization
- Doctrinal use of quick exit criteria along safe-haven pathways through the building
- Command center control and communications with all building components, local authorities, and other buildings on the electromechanical building support network
- Baseline immune building architecture for the incorporation of new, evolving technologies

Technology Enablers

Cost notwithstanding, technologies are available today that could bring the hypothetical benefits listed above to fruition. Computer-based feedback and control of building HVAC systems for climate and smoke hazard situations have made significant progress over the last 5

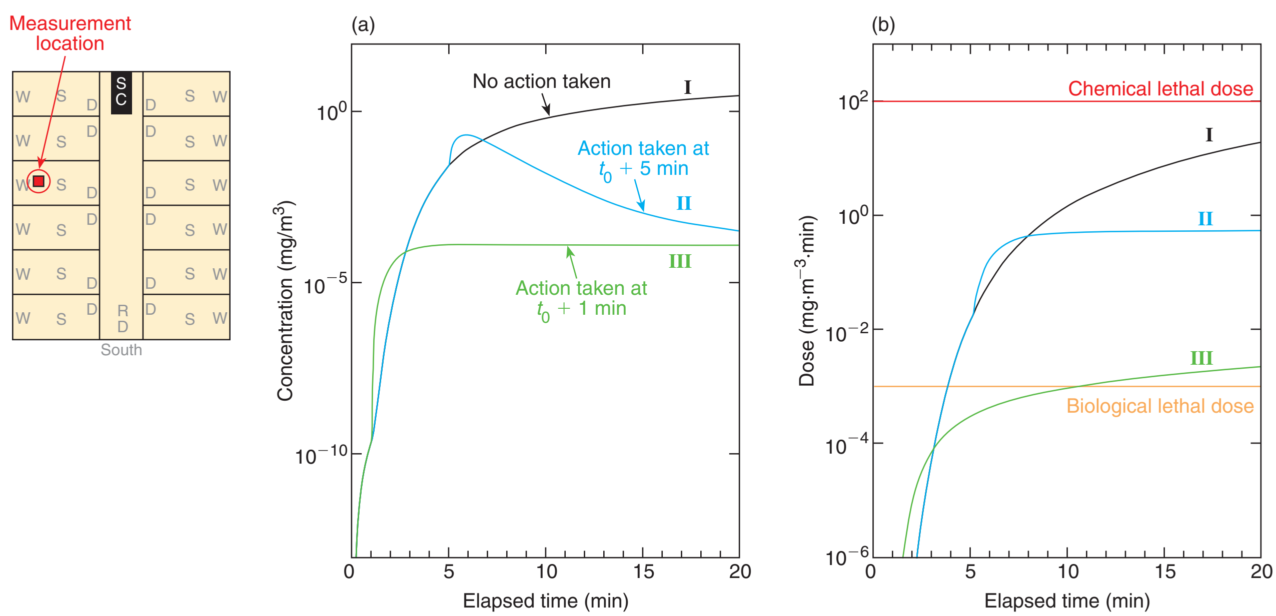

Figure 3. Comparison of the concentration and dose/time evolution (constant release of 5 mg/s) for actions taken at t_0 + 1 and 5 min after contamination onset: (a) instantaneous concentration, and (b) cumulative dose, showing chemical and biological lethal dose thresholds for nominal nerve gas and anthrax substances, respectively.

years.[4] A variety of biological triggers based on particle size discrimination and ultraviolet (UV) fluorescence (Fig. 4) are commercially available to sound alarms and initiate feedback. Biological sensors, such as the biosensing Time-of-Flight Mass Spectrometer,[5,6] are maturing to the point where they are available for initial proof-of-principle deployment in real facilities to assess their detection speed, identification capability, and susceptibility to false alarms. Bioneutralization instruments that will sterilize pathogens in the airflow and on interior HVAC components are being tested today using several UV light and chemical treatment methods. UV light germicidal methods have been used for health care and food preparation for decades. High-efficiency particulate air (HEPA) filters continue to be refined for wider particle capture range while maintaining 99.99% capture efficiency at lower pressure drop. Chemical sensing is attainable by a variety of commercially available products (Fig. 5), many of which are described by the Chemical and Biological Defense Information Analysis Center.[7] The use of Gas Chromatography/Mass Spectrometry (GC/MS) offers rapid, yet specific, characterization of airborne chemicals, and activated carbon filters are being improved to adsorb harmful chemicals with increased contact time with the contaminant.

Sensor Performance Criteria

Continuous sensor surveillance is a major part of the immune building concept. Strategically placed sensors can provide the trigger function for alarms and the feedback function to HVAC control systems. These sensors may be outside the facility to monitor the external environment and inside the facility at selected locations to monitor the inside environment and the functionality of immune building operating systems.

Sensors must be able to sense and measure both the threat (e.g., chemical, biological, toxic industrial compounds) and the background (e.g., ordinary biological remnants from plants, animals, and human processes as well as ordinary chemical substances from cleaning, printing, lubrication, etc.). Furthermore, it would be useful if the sensed materials were characterized in the form of air concentration (mg/m^3) and potential cumulative dose (mg/m^3 $\times$ min) since the dose is the time-integration of the concentration. Another major concern is the dissemination rate of the threat agent that arises from different dissemination sources. That is, the infusion, rate of growth, and rate of decay of the threat agent need to be measured and predicted for various dissemination scenarios in order for subsequent design and testing to occur. These time-varying functions will not only drive the expected concentrations but also dictate requirements on sensor sensitivity and sensor response time.

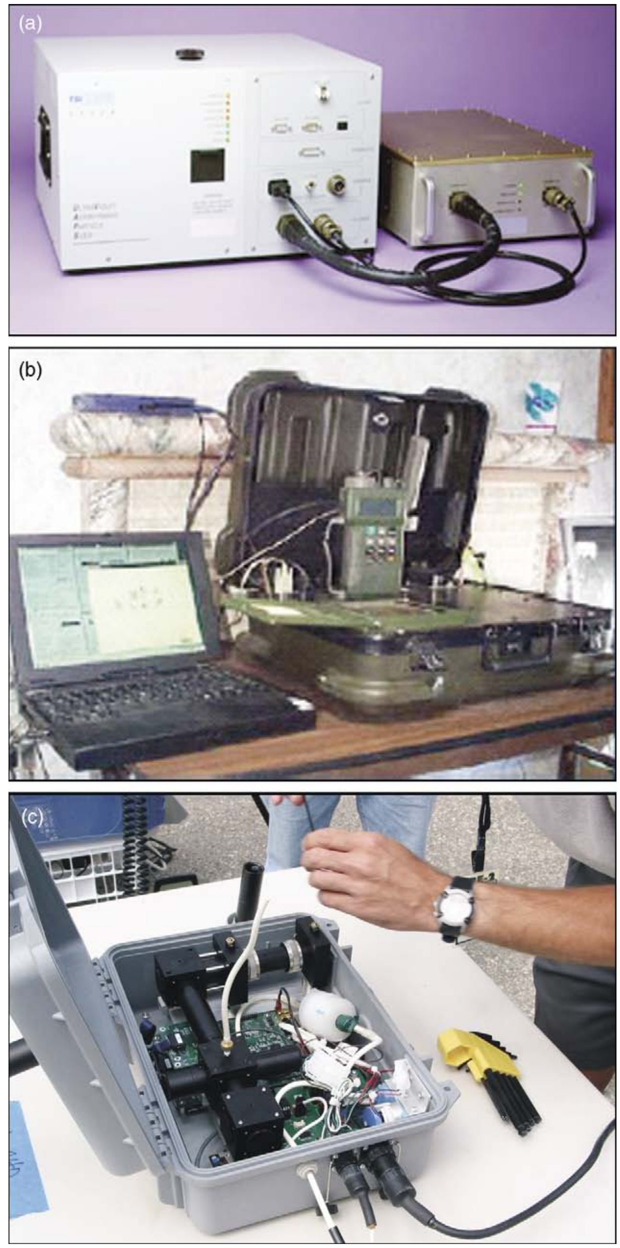

Figure 4. A variety of ultraviolet triggers: (a) the TSI Inc. UltraViolet Aerodynamic Particle Sizer (UVAPS), (b) MIT Lincoln Laboratory BioAerosol Warning Sensor (BAWS), and (c) S3I Corp. 740 Biological Trigger.

Building Protocols and CONOPS

As a surveillance, monitoring, and control system, the immune building is a dynamic, continuously operating system that reacts to its environment. The basic operating precepts are shown in Fig. 6. External air is continuously filtered before it enters the heart of the HVAC system. In the center of the HVAC system is a centralized neutralization processor (CNP) that precipitates and/or destroys the viability of biopathogens (e.g., UV radiation) and also decomposes dangerous chemicals (e.g., catalytic converters). The resultant "clean" air is then passed through filter banks as a source of supply

Figure 5. A variety of commercial chemical sensors rely on ion mobility spectrometry, surface acoustic waves, and electrochemical reaction for detection. They offer reliability, orthogonality, sensitivity, and specificity: (a) Shipboard Automated Chemical Agent Detection Alarm (ACADA), (b) Centurion field tester, (c) Graseby Ion Detector (GID-3), and (d) CW Sentry Plus.

air to the occupant space. After circulation through the occupant space, the air is returned to the HVAC CNP and the air handling process.

Rules of engagement need to be developed that set sequential response protocols and best practices of sensors, mechanical systems, containment levels, and security response based on

- Whether the detected substance is chemical or biological (chemical agents require more rapid response than biological agents)
- How the detected substance differs from other hazardous materials such as smoke and toxic industrial compounds
- The detected concentration levels
- The priority of the contaminated spaces

If a low-level threat is detected, an extra-low-level collection reservoir will contain the threat remnants and low-level local neutralization in each affected occupant space will be invoked. If a large amount or high level of threat is detected, a high-surge collection reservoir, local surge neutralization, and new air from a safe air reservoir will be invoked. Not shown in Fig. 6 are the feedback and control of shutters, vents, exhaust fans, and other HVAC apparatus that are also invoked according to the Chem-Bio Alarm Level (CBAL) to be discussed next.

Figure 7 gives the elementary CONOPS for the immune building. All operations revolve about a command center (either inside the immune building or elsewhere). The command center continuously receives data from the HVAC and CNP as well as chem-bio and environmental sensors placed in and about the building. On occasion, detailed environmental background assays for ambient chemical compounds and biological species are performed and stored at the command center library. The results of periodic calibrant releases throughout the building are also stored in the "habits" library. The command center provides sensor and data processing displays to operators and a central processor, which

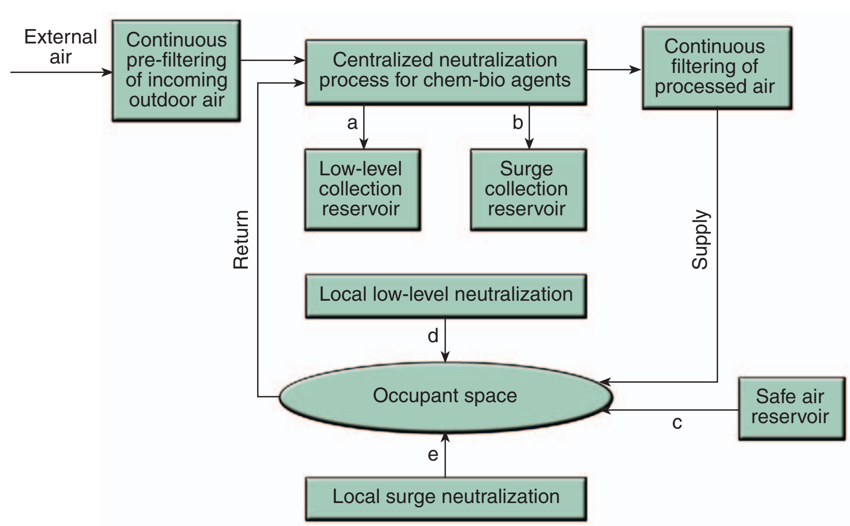

Figure 6. A building monitoring protocol, with sensors located throughout the building, for processing and channeling filtered, neutralized, and clean, safe air through the occupant space (a–e are invoked only when potential agents are present).

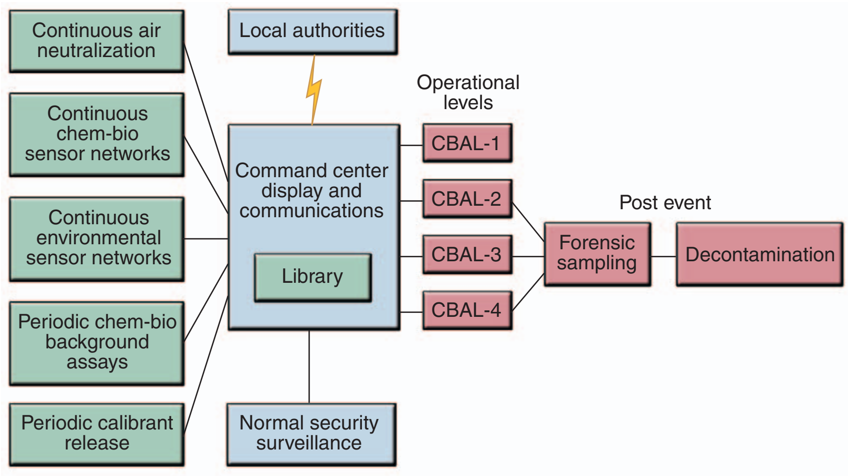

Figure 7. Elementary CONOPS that entail the use of both legacy and real-time data are collated and analyzed at the command center to establish chemical-biological alarm levels (CBALs) and remedial actions.

For example, CBAL-1 is the operational level under normal background conditions where the HVAC system runs normally with centralized neutralization. CBAL-2 is proclaimed when the presence of any agent is detected up to the 0.1 ED_{50} level. Here, the authorities are contacted, the surveillance system begins to localize the threat, HVAC controls are invoked to reduce the contamination and contain the threat, and the low-level collection reservoir is opened. CBAL-3 and -4 outline further operations, including evacuation (Table 1).

together declare CBAL operational levels. These levels might be associated with "accepted effective dose 50" or ED_{50} (dose at which symptoms occur in 50% of the exposed population) values for each agent detected. Table 1 describes these levels that have concomitant rules of engagement for each threat and sustaining operations that include HVAC settings and evolutions, alarm presets, evacuation paths, and communications.

FUTURE CONSIDERATIONS

Immune Building Strategies

A variety of building strategies and technologies need to be explored to address goals such as inhabitant protection, functional restoration, and forensic capability and to provide operations with reasonable life-cycle cost. As shown in Fig. 8, the foundations for each strategy are the basic considerations for HVAC configurations and zonal

Table 1. Chemical-biological alarm levels (CBALs) and concomitant building operations for establishing collective countermeasures.

Immune building operations*	CBAL-1 (normal background)	CBAL-2 (up to 0.1 ED_{50})	CBAL-3 (0.1 to ED_{50})	CBAL-4 (>ED_{50})
Maintain normal operating status	x			
Contact authorities		x	x	x
Begin threat localization		x	x	x
Use HVAC dynamic feedback and control to reduce threat concentration		x	x	
Use specific HVAC control to contain threat and provide safe routes				x
Alarm occupants			x	x
Initiate voluntary evacuation along selected routes			x	x
Initiate manditory evacuation along safe routes				x
Apply surges of safe air at selected locations			x	
Apply surges of safe air along safe routes				x
Apply central neutralization	x	x	x	x
Apply both local and central neutralization			x	x
Open low-level collection reservoir		x		
Open surge collection reservoir			x	x

*Does not inlcude medical intervention, quarantine, crowd control, or tagging.

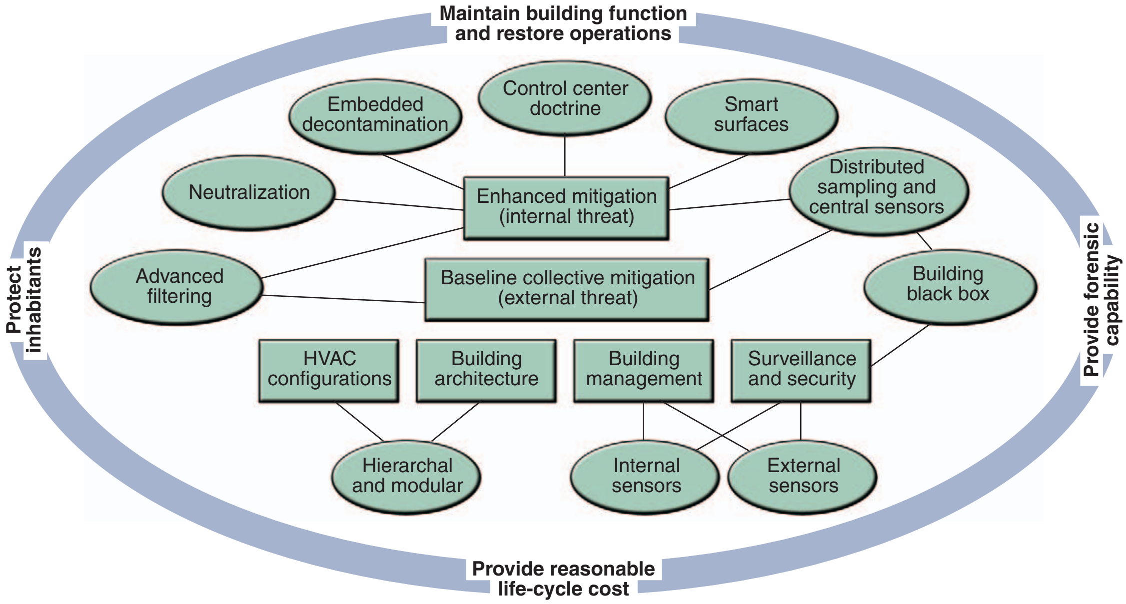

Figure 8. Different concerns and technologies are confronted depending on where one enters the "football" diagram. If the strategy is principally to protect inhabitants, then advanced filtering and neutralization issues are confronted, etc.

coverage, building architectural design for containment and flexibility, building management system (BMS) for optimal circulation, and air control and normal security surveillance measures. Baseline collective mitigation, especially for an external threat release, is expected to be enhanced with advanced filtering methods. Added neutralization capability will lead to enhanced mitigation against internal threat release. Novel embedded decontamination-by-command apparatus along with the potential for smart walls/ceilings should allow rapid decontamination or perhaps self-decontamination to restore operations. A control center will provide overarching control over the threat situation based on inputs from the BMS, sensors, and surveillance devices. Distributed sampling ports leading to a central sensor bank will provide not only indications and warnings for contaminant concentrations and doses, but also data to the building black box in continuous fashion for forensic capability.

Technical Issues and Testing

There are also many technical issues and testing concerns that need to be resolved in a build-test-build countermeasures situation since one glove does not fit all the combinations and permutations of threat agent, attack scenario, and performance criteria. Facilities such as the APL Chemical and Biological Test and Evaluation Center (see the article by Carlson et al., this issue) can help provide data on filter efficiencies as a function of particle shape anisotropy and hydrophilic/hydrophobic properties, pathogen viability along the HVAC mechanical chain, re-aerosolization off filter/duct/wall surfaces, and pathogen neutralization methods. For chemical agent threats, the filters must be evaluated in a chemical taxonomy for their ability to resist breakthrough and their performance under different loads. Other issues include characterization of filter deterioration and toxic outgassing, evaluation of decontamination methods in both the inhabitable spaces and in the HVAC mechanical chain, and evaluation of sensors and control devices in multimode situations where multiple challenges (chem, bio, smoke, etc.) might be congruent. There will be a never-ending progression of sensor testing and environmental background characterization to assess sensor sensitivity and specificity as well as sensor compromise or degradation.

SUMMARY

In anticipation of further chemical and biological attacks of great severity, the technologies and strategies for immune building–type countermeasures are now being discussed among building design, construction, and policy experts.[8,9] Clearly, not all facilities can afford or warrant the countermeasures suggested here, especially those smaller than, say, 50,000 square feet (an arbitrary value). It has been estimated that a complete system might cost as much as $13 million for a 50,000 square foot facility.[10] Technology investigations and demonstrations will help to educate built-environment stakeholders and the general public about the need to implement sensors, active feedback and control, and event preparedness exercises together to protect the 50% of the

American workforce that occupy buildings larger than 50,000 square feet. We must remember that the value of chem/bio countermeasures is not as much a decision driver as concerns about crime, business decline, natural disasters, and government regulation. Nevertheless, built-environment professionals are beginning to appreciate the need for high-value buildings in certain operational venues to provide enhanced capability against chemical and biological terrorism.

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