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Defensive Filtration

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A building's air filtration system can serve as a significant defense component during an airborne chemical and/or biological attack from an external release. To assist building owners and designers in risk analysis and management decisions, this article provides a general introduction to biological and chemical agents considered most likely to be used in a terrorist attack. HVAC system safeguards are discussed, followed by a description of air filters suitable for use in the chemical and biological arena. An internal release directly to the indoor environment poses additional challenges and solutions that are beyond the scope of this article.

Biological Agents

The Centers for Disease Control (CDC) has categorized biological agents in terms of dissemination and mortality.¹ The U.S. government considers the more stable, reliable, effective, and deliverable of these agents as potential weapons.

The most frequently cited candidates for use as biological weapons are anthrax, botulism, plague, smallpox, tularemia, and a variety of hemorrhagic fever viruses² (see *Bacteria and Viruses* sidebar).

Bacteria range in size from 0.3 to 35 microns in diameter. Viruses are 0.01 to 0.3 microns. For an idea of how small bacteria and viruses really are, the pe-

riod at the end of this sentence is approximately 300 microns in diameter.

If bacterial and viral agents are aerosolized, the aerosol particle size must be just right to float as a fog through the air. Aerosol particles between 0.5 and 5 microns in diameter typically are retained within the lung. Smaller particles can be inhaled, but most are exhaled. Particles larger than 5 to 15 microns lodge in the nasal passages or trachea and do not reach the lung. Aerosol particles that are larger than 15 to 20 microns tend to settle to the ground.

Another form of biological weapon is a toxin, which is any toxic substance that can be produced by an animal, plant

or microbe (see *Toxins* sidebar). Toxins, unlike bacterial and viral agents, do not reproduce. Only one class of easily produced toxins, the trichothecene mycotoxins, is dermally active. Therefore, the most likely mode of delivery is by respirable aerosol, contaminated food or water (although the latter is difficult in chlorinated water and because of dilution effects).

Because they probably are delivered as respirable aerosols, toxins as an effective mass casualty bioweapon (MCBW) are limited by their toxicities and ease of production. Most of the less toxic agents cannot be produced in sufficient quantity with current technology. Stability of toxins after aerosolization is also an important factor and further limits toxin weapon effectiveness.

It is difficult to develop real-time toxin detectors for several reasons. Unlike chemical agents, which might be detectable for hours, toxins might be detectable in the air at one location, and only for a few minutes. Furthermore, toxin detectors (with the present state of technology) would need to have the specificity to identify a toxin and differentiate it from other organic material in the air.

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As a general rule, the decontamination procedure recommended for chemical warfare agents effectively destroys toxins. Household bleach at various concentrations and exposures destroys most toxins. Soap and water, or even just water, can be effective in removing most toxins from skin, clothing and equipment.¹¹

Chemical Weapons

Chemical agents that might be used by terrorists range from warfare agents to toxic industrial chemicals. Once made, chemical weapons can last from a few months to 50 years, depending on the purity and storage method. Delivery methods include non-exploding means such as an open gas cylinder, an open container of liquid agent left to evaporate, aerosol generator, spray tanks, or by a small explosive charge.

Generally when exposed to the elements, chemical weapon agents tend to degrade or disperse without human intervention. The time typically varies from a few hours to a few weeks.¹²

The categories of military chemical weapons are nerve agents, blood agents, blister agents, choking agents, tear gas agents, incapacitants or psychochemicals, and industrial chemicals (see *Chemical Agents* sidebar).¹³ Some agents are gases. Others need to be delivered as aerosols. A discussion of potential industrial chemicals that could be used in a terrorist attack is beyond the scope of this article.

HVAC System Safeguards

Many HVAC system construction features can provide a measure of protection against entry and/or circulation of the previously described chemical/biological (C/B) agents through the air-handling systems. The following is a summary of some of those safeguards.

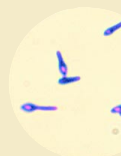
- The supply and return ducts entering each public lobby need to be provided with quick-closing isolation dampers. These dampers can be manually activated by a continually manned guard booth located at each respective entry. Dedicated exhaust systems serve each public lobby.
- Air balance non-public areas to have a slightly positive pressure with respect to public areas. Non-public areas should be air balanced to provide a slightly positive pressure with respect to the outdoors.
- Locate outside air intakes at the top of the building or, if at grade level include perimeter security. This may consist of full-size, solid walls surrounding each intake, sloped bird screen top, and wide-angle cameras and illumination.

Bacteria and Viruses

Anthrax is a disease caused by the spore-forming *Bacillus anthracis* bacterium. The rod-like bacteria are about 1 micron diameter by 3 to 5 microns in length. Anthrax spores are 2 to 6 microns in diameter. Humans become infected through skin contact, ingestion or inhalation. Anthrax, in liquid form, is difficult to effectively aerosolize. Currently, no atmospheric warning systems can detect an aerosol cloud of anthrax spores.³

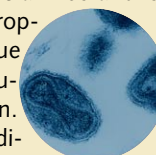


Botulism is a breathing muscle-paralyzing disease caused by *Clostridium botulinum* bacteria. Botulism is generally transmitted by ingesting contaminated food, and is not spread from person to person. Available anti-toxin is effective in reducing the severity of symptoms with full recovery in a few months.⁴ Aerosolization is a possible delivery method.



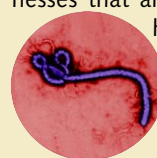
Plague is a disease caused by the *Yersinia pestis* bacteria, which can infect the lymph, blood or lungs. Bioterrorism-related outbreaks are likely to be delivered through dispersion of an aerosol. Person-to-person transmission is possible via large respiratory droplets in face-to-face contact. Post-exposure prophylaxis is available.⁵

Smallpox is an illness caused by the variola virus and is transmitted via large and small respiratory droplets. It is considered a bioterrorism threat due to its high morbidity in a non-immune population and its ease of airborne transmission. Death occurs in about 30% of untreated individuals. For people exposed to smallpox, the vaccine can lessen the severity of or even prevent illness if given within three days after exposure.⁶



Tularemia is a disease caused by the *Francisella tularensis* bacteria, which is 0.2 micron diameter by 0.2 to 0.7 micron length. An aerosol release is considered the most likely delivery mode by terrorists. Human-to-human transmission is not known to occur. Post-exposure prophylaxis is available.⁷

Viral Hemorrhagic Fever (VHF) refers to a group of illnesses that are caused by several families of viruses. All hemorrhagic fever viruses have some degree of aerosol infectivity. The degree to which real-world (not confined labs) aerosol transmission is possible has not been fully studied.⁸ Scientists believe these sorts of viruses are difficult to obtain and cultivate and are less likely to be used in a bioterrorist attack.⁹



Tuberculosis is not considered a likely candidate for a bioterrorist attack. TB bacteria (*Mycobacterium tuberculosis*) float in tiny airborne water droplets. It usually takes repeated exposure for the bacteria to lodge in the lungs. Even when exposed, most people don't become infected, but rather the bacteria lie dormant in the lungs' air sacs.¹⁰

Toxins

A few toxins, such as Staphylococcal enterotoxin B (SEB), can cause illness at extremely low doses, but relatively high doses are required to kill. Therefore, lethality alone is not an appropriate criterion on which to base a toxin's threat potential. In addition, less potent toxins could be significant threats as aerosols in a confined space, such as a building.

Of the approximately 400 known toxins, 17 are deemed "most toxic" (all bacterium-produced), 73 are "highly toxic" (12 bacterium-produced, five plant-produced, and the remaining produced by other organisms and animals), and 305 "moderately toxic" (20 bacterium-produced, 31 plant-produced, and remaining produced by other organisms and plants).

The "most toxic" toxins could probably be used as a MCBW. The "highly toxic" toxins could probably be used in closed spaces such as a building or as effective terror weapons in the open.

The "moderately toxic" toxins likely are useful only as assassination weapons, which require a direct attack against an individual.

The most toxic biological materials known are protein toxins produced by bacteria. They are generally more difficult to produce on a large scale than are the plant toxins, but are many times more toxic. Botulinum toxins, the staphylococcal enterotoxins, diphtheria and tetanus toxin are well-known examples of bacterial toxins.

Toxins derived from plants generally are easy to produce in large quantities at minimal cost in a low-tech environment. A typical plant toxin is ricin, a protein derived from the bean of the castor plant.

- For stairway emergency ventilation with an intake at low level, HEPA filters can be installed in the ductwork, including modification to any existing associated fans. The higher grade of filtration can be justified because of the critical nature of stairs and the concentration of people in a confined area when used as emergency egress. Anthrax spores are difficult to clean on a large scale, such as a stairway.¹⁴ A week or multi-week closure of stairways would virtually shut down the entire building because of inadequate egress.

- Install air filters within each return and/or outside air-handling system. Select filters that are commensurate with anticipated type(s) of chemical/biological threats. The filter bank can be installed in series with the main air-handling unit for continuous filtration, or in a by-pass configuration for switched-in C/B filtration.

Effective C/B detection as part of an automatic sequence of operation in building ventilation systems is not yet available. Chemical agent detection is limited because of shortcomings in response time, false alarms, broad-spectrum capability and maintenance. Biological agent detection is not available in real time.¹⁵

Air Filtration Types and Supplements

In addition to HVAC safeguards, air filtration can provide another line of defense against a C/B release. Three major types of filters, which have performances suitable for C/B filtration, are described next. In addition, various hybrid additions are available to supplement these filters.

HEPA Filter

The HEPA (High-Efficiency Particulate Filter) was developed during World War II by the Atomic Energy Commission to remove radioactive dust particles from research space. Today, HEPA filters are used for nuclear contamination, asbestos abatement, surgical facilities, TB wards, clean rooms, computer rooms and other critical areas that have high-efficiency air filtration needs.

The filtration media is glass microfiber paper pleated back and forth, separated with corrugated aluminum fins and housed in a

wood or metal cartridge. This type of filter can operate in a range of conditions (up to 100% rh and to at least 250°F [121°C]).

These filters are 99.97% efficient in capturing 0.3 micron-diameter particles.¹⁶

Historically, 0.3 microns was calculated to be the most difficult size to capture (not larger, nor smaller). That is why HEPA filters are rated based on this particle size. HEPA filters are more efficient at larger than 0.3 microns and improvements in media manufacturing have resulted in even higher efficiencies.

Most known bacteria range in size from 0.2 to 5 microns in diameter. Viruses are between 0.01 and 0.3 microns in size. However, since viruses need a host to live, they usually are attached to a bacteria or other large object such as a water droplet (0.5 to 5.0 microns).

The standard HEPA filter has an initial 1.0 in. w.c. (249 Pa) pressure drop at 250 fpm (1.3 m/s) face velocity. A high capacity HEPA filter has a 1.4 in. w.c. (348 Pa) pressure drop at 500 fpm (2.5 m/s), with the same quality air filtration. Dirty filters have an air pressure drop of between 2.0 to 2.3 in. w.c. (498 to 572 Pa).

HEPA filters can be installed in either side access housing (bag in/out or simple slide in/out) or face loaded in a builtup support grid. The sealing between the filter body and the housing is either by a gasket or gel. The filter-to-housing gasket seal is effected by a locking mechanism that forces the filter against a continuous flat mounting surface on the interior of the housing, which mates to a perimeter gasket on the filter. The gasket seal technique is the conventional method of sealing filters within HVAC housings and is considered reliable.

The filter-to-housing fluid seal is affected by means of a continuous knife-edge on the interior of the housing, which mates into the gel-filled perimeter channel on the face of the filter. To effect the seal, the locking mechanism forces the filter against the knife-edge. The knife-edge penetrates the gel and a uniform seal is produced on the filter face. For a continuous high hazard application, bag in/out side access housing is used exclusively.

High-Efficiency Filters

90–95% (MERV 14), 95% (MERV 15), 95% DOP (MERV 16)¹⁷

High-efficiency filters are constructed similarly to HEPA filters, except the frame is available as a bag or in a cartridge configuration. The construction of bag filters is not as sturdy as cartridge filters. Therefore, during changing and disposing of filters, cartridge filters are less likely to re-entrain captured particles into the ambient air.

Filtration efficiency ranges from 90% to 99% for anthrax bacteria (1 micron) and near 100% for the spore state (2 microns), which is somewhat similar to HEPA filter efficiency (99.97% at 1 micron). However, for smaller pathogenic bacteria and water droplets carrying viruses that are between 0.2 and 0.5 microns, the efficiency drops to the range of 60% to 95%. These filters cannot guard against chemical gas attack.

At 500 fpm (2.5 m/s) face velocity, the clean filter pressure drop ranges from 0.4 to 0.85 in. w.c. (40 to 211 Pa) depending on efficiency and cartridge or bag housing. Installations for side access or front loading are available. With the upgrade in filtration efficiency, gasketing around the housing channel should be considered.

These filters are a cost-effective alternative to HEPA filters when very high filtration of submicron particles (< 1.0) is not required. They cost less, impose less air pressure demand on the fan motor, and tend to require less retrofit work to an existing air-handling system. An analysis should be performed to estimate the reduction in airflow.

Activated Carbon Filter

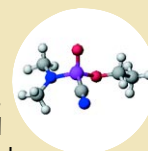
Before activated carbon is explained, an understanding of how carbon works with odors, gases and vapors is required. Activated carbon adsorbs (not absorbs) airborne odors and vapors. When a material adsorbs something, it attaches to it by chemical attraction. The huge surface area of activated carbon gives it countless bonding sites. When odors and vapors pass next to the activated carbon surface, they attach to the surface of the carbon. To be absorbed by carbon, odors and vapors would have to be diffused into the carbon, not simply attached to its surface.

Common substances used as the base material for producing carbon are wood, coal and coconut shell. These base materials are subjected to carbonization, which is a heating process whereby the base material is subjected to high temperatures, which drives out any volatiles.

To activate the carbon it is subjected to a second heat and steam treatment. The activation of the carbon is what gives it its unique adsorption characteristics.

Activation creates a highly porous carbon, which provides a large surface area for adsorption. Impregnating the carbon with special chemicals to be a more effective adsorbent can enhance activated carbon.

Chemical Agents



Nerve Agents: These chemical agents, when inhaled, ingested, or absorbed through the skin, result in uncoordinated muscle contractions, followed by paralysis, and leading to death.*

- **Tabun** (GA) is a brownish to colorless liquid that gives off a colorless vapor. GA was the first of the nerve agents developed by the Germans before World War II.

- **Pure sarin** (GB) is odorless and colorless. This agent vaporizes very easily.

- **Soman** (GD) is a colorless liquid that gives off a colorless vapor. Soman is the most poisonous of the G-agents, because of the ease with which it can penetrate into the central nervous system.

V-Agents (VX, VX2): These agents are oily liquids with high boiling points. They are primarily a contact hazard and are extremely toxic. The slight amount of vapor given off is sufficient to be an extreme hazard.

Blood Agents: The body absorbs these chemical agents primarily by breathing. Most blood agents are cyanide-containing compounds. Hydrogen cyanide (AC), cyanogen chloride (CK), and arsine (SA) are the important agents in this group. Blood agents are highly volatile and, therefore, nonpersistent even at low temperatures. These agents can be dispersed by artillery shell, mortar, rocket, aircraft spray, or bomb.*

Blister Agents: Both exterior and interior parts of the body readily absorb these chemical agents. These agents cause inflammation, blisters, and general destruction of tissues. Agent vapors attack moist tissue. Blister agents may be delivered in colorless gas or liquid form.*

Choking Agents: These chemical agents, phosgene (CG) and diphosgene (DP), irritate and inflame tissues from the nose to the lungs, causing a choking sensation. CG is a colorless gas with an odor similar to that of new-mown grass. It was first used during World War I. The gas tends to hug the ground.*

Tear Gas Agents: These compounds (agents produced in the United States are known by the following symbols: CS, CS1, CS2, CSX, CR, CN) cause a large flow of tears and irritation of the skin. Some of these compounds are very irritating to the respiratory tract. They sometimes cause nausea and vomiting. Outdoor exposure has only transient effects. However, when released indoors, they can cause serious illness or death.

Incapacitating agents are chemicals that cause physiological or mental effects that lead to temporary disability. Incapacitating agents differ from other chemical agents in that the lethal dose is many times greater than the incapacitating dose.

*The U.S. Army has detectors for these agents that are intended only for battlefield applications.

Activated carbon adsorbs to its surface. When no more surfaces are left to adsorb to the carbon, it is depleted of its effectiveness. Large amounts of carbon last longer than small amounts because there is more surface area for adsorption. The more contact time activated carbon has with a pollutant, the better chances of adsorption. This contact time is called residence and is measured in seconds. Typical residence time ranges between 0.1 to 0.3 seconds for non-industrial building applications.

Thicker carbon filters are better for adsorption. If the pollutant travels through a long maze of activated carbon, its chances are greater of being adsorbed. Granular activated carbon is more effective than a 1 or 2 in. (25 or 50 mm) thick impregnated carbon pad.

Granular activated carbon has more surface area for adsorption than an impregnated pad. Also, an impregnated pad will have to be changed more frequently.

A broad-based chemical addition typically used is ASZM-TEDA (copper, silver, zinc, and molybdenum-triethylenediamine). This is currently considered by U.S. Department of Defense and the U.S. Department of State to be the most effective collective filtration for industrialized and militarized chemicals, when used in conjunction with an adequate residence time across the carbon bed. At 200 fpm (1 m/s) face velocity, the air pressure drop typically is 1.6 in. w.c. (398 Pa). Unlike particulate filters, air pressure drop for a carbon filter remains constant during loading.

Due to the toxic duty typically seen by carbon filters, they are usually housed in a stainless steel side access configuration. For industrial grade carbon filters, the housing for the HEPA and carbon filters are combined into a single side-access unit with individual doors. This housing can be either bag-in/bag-out or non-bag-in/non-bag-out. The bag-in/bag-out arrangement is used to minimize exposure to harmful contamination while replacing and handling dirty filters. The housing includes a ribbed bagging ring behind the access door, over which a PVC bag is attached. Once the initial filters are installed and the first bag attached, all filters are handled through the bag. The sealing between the filter body and the housing is either by a gasket or gel. A gel seal is considered the most airtight seal for particularly high hazard duty.

The 24 × 24 × 12-in. (609 × 609 × 305 mm) deep carbon trays weigh approximately 160 pounds (72 kg) each. Therefore, a 24 × 12 × 12-in. (609 × 305 × 305 mm) deep tray with change-out side platform is offered to ease high-level filter changing. Careful coordination between the architectural room plan and structural floor supports is required for carbon filters and housing due to their increased weight. This degree of filtration provides a high degree of survivability against most known C/B attacks.

Antimicrobial Treated Filter

Several filter manufacturers offer low- and medium-efficient filters with an antimicrobial agent applied. However, no consensus exists in the industry to recommend these filters for anywhere but residential applications.¹⁸ Direct contact is required for an antimicrobial agent to destroy microorganisms. Dust buildup tends to inhibit direct contact. There is no evidence that microorganisms that lodge downstream within the filter media are inhibited or killed.

Ultraviolet Light Emitter

Ultraviolet is between visible light and X-ray on the electromagnetic spectrum. Scientists have classified UV light into three bandwidths. UV-A, also known as blacklight, has a long wavelength with low body penetrating ability. Exposure causes skin tanning, is used medically to treat skin disorders and is generally harmless. UV-B has a shorter wavelength and a high body penetrating ability. Prolonged exposure leads to skin cancer and cataracts. UV-C has a specific wavelength of 253.7 nanometers. It has an extremely low penetrating ability, being absorbed by the outer layer of dead skin. This wavelength does not penetrate to the lens of

the eye. However, overexposure may cause reddening and irritation of the eyes. Because of the high output of the light tube emitters, manufacturers recommend either a switch or access door interlock contact. Based on NIOSH guide-

‘Much of the research regarding UV-C energy effectiveness has been geared toward ... the medical and food service industry, not the rare bacteria used in bioweapons.’

lines, an exposure of 1 minute at 0.3 ft (1 m) from a tube would begin to irritate the eyes.

UV-C has been used as a germicide in health care, food processing, and waste treatment industries for more than 50 years. UV-C penetrates all bacteria, viruses, and molds, modifies their DNA, which prevents the microorganism from reproducing and leads to its death.

The germicidal effectiveness (kill rate) is directly related to the UV dose applied, which is a function of time (seconds) and irradiance (microwatts per square centimeter). The unit of measurement for exposure level is microwatts per second per square centimeter.

UV-C emitters were first applied to the HVAC industry about six years ago to clean condensate drain pans and cooling coils in large air-handling units. Recently, there has been interest in applying UV-C emitters as a protection against bioterrorist attack. Much of the research regarding UV-C energy effectiveness has been geared toward microorganisms present in the medical and food service industry, not the rare bacteria used in bioweapons. Based on various reports, anthrax in the bacteria state needs 5,000 to 9,000 microwatt per second per square centimeter to kill it, while 22,000 are required in the spore state.

Manufacturers offer UV-C emitter models suitable for in-duct or large plenum installations. It is generally recommended for airstream use that the air temperature be above 45°F (7°C) (lamp energy output is decreased 15% at 32°F [0°C]), although this varies somewhat by manufacturer. Recommended air velocity is from 300 to 400 fpm (1.5 to 2 m/s). At 500 fpm (2.5 m/s), closer tube spacing is required. As with ordinary light bulbs, a dirty surface reduces output. Lamp life of a typical 24-in. (609 mm), 70 watt UV-C tube is approximately one year of continuous use. Benefits include some, although perhaps limited, ability to kill microorganisms in the airstream passing by the light tubes and the ability to sanitize the surface of filters. However, HEPA filters, because of their deep and dense construction, cannot be sanitized using UV-C emitters.

Because of the previously described variables, that affect the killing ability of UV-C emitters, they should only be considered as a supplement to air filters for purposes of bioterrorism defense.

Electrostatic Air Cleaner with UV Emitter

This hybrid filtration system consists of a low wattage electrostatic air cleaner with a UV-C emitter installed upstream. The air cleaner is available in any module size in a flat or v-bed configuration, side or face loaded. At 500 fpm (2.5 m/s) face velocity, the clean pressure drop is about 0.16 in. w.c. (40 Pa). Its filtration efficiency is about 95% at 1-micron particle, and with 0.5 to 0.3 micron particles, its efficiency drops to 75% to 33%, respectively. It is currently used in several applications, including control of contaminants in labs and hospitals and removal of cigarette smoke in the hospitality industry.

The air cleaner uses a high-voltage, low-current dc charge that is continuously applied to the conductive center screen of the disposable 1 or 2 in. (25 to 50 mm) thick media pad. This creates an electrostatic field between the center screen of the disposable media pad and the filter frame. This force field polarizes the surface charge of both the fibers of the media pad as well as the particulates that are drawn into the filter. The polarized particulates are then attracted and attach themselves to the polarized fibers and are removed from the airstream. In this way, the low-density media is able to achieve high efficiencies with a low static pressure drop. The media pads are changed approximately every six months. Once pathogens are captured on the media, they are inactivated with UV-C illumination.

Summary

Implementation of the filtration options discussed in this article in concert with the other HVAC system-related safeguards will reduce the likelihood of loss of life and mass contamination of the facility via the introduction of biological and/or chemical contamination in the outside airstream. To

assess the overall vulnerability of a facility, a thorough threat analysis should be performed.

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