Recent terrorist events have increased interest in the vulnerability of buildings to CBR threats. Of particular concern are building HVAC systems, because they can become an entry point and distribution system for airborne hazardous contaminants. Even without special protective systems, buildings can provide protection in varying degrees against airborne hazards that originate outdoors. Conversely, the hazards produced by a release inside a building can be much more severe than a similar release outdoors. Because buildings allow only a limited exchange of air between indoors and outdoors, not only can higher concentrations occur when there is a release inside, but hazards may persist longer indoors.

The results of the FEMA 452 risk assessment, including the vulnerability checklist, will likely yield many opportunities to reduce risk over time by upgrading the building's HVAC and other systems. This chapter describes the nature of the CBR threat and some of the opportunities for risk reduction.

4.1 OVERVIEW OF CBR THREATS

There are hundreds of toxic chemical, biological, and radiological agents that could be released in an accident or terrorist attack. Among them are chemical-warfare agents, industrial chemicals, radioactive materials, toxins, irritants, incapacitants, and biological agents, which are mainly bacteria, viruses, and rickettsiae. The potential hazard each agent presents is determined by its toxicity, persistence, and quantity.

Toxicity among these agents varies over several orders of magnitude. Toxicity and likely quantity of exposure determine the level of protection needed for protective systems. Toxic agents also vary widely in persistence. Gases such as chlorine are non-persistent and usually dissipate in minutes outdoors. Radiological agents and some of the biological agents are extremely persistent and may remain toxic in an indoor or outdoor environment for decades unless decontamination measures are undertaken.

Toxicity and persistence determine the extent and duration of a hazard, but the more important characteristics relative to protective strategies are how readily the agents can be filtered and detected. Filtration involves the removal of a toxic agent from an air stream. The full spectrum of toxic agents includes gases, vapors, and aerosols (finely divided particles). With current technology, filtering the full spectrum of toxic agents requires three different processes—mechanical filtration for aerosols, physical adsorption for chemical agents of low vapor pressure, and chemisorption for chemical agents of high vapor pressure. The latter two are usually incorporated into a single filter called an adsorber.

With regard to detection, most of the toxic chemicals have warning properties; that is, they can be detected by the human senses—by smell, irritation of the eyes/respiratory tract, color, and in some cases by taste—before severe effects occur. There are no warning properties associated with airborne microbial pathogens or radioactive aerosols.

Most toxic chemicals produce immediate effects. Automatic detectors are available for the accurate detection of a few of the most toxic chemicals. Single-pass filtration systems of the high level of efficiency necessary for protection against toxic chemicals are generally expensive and cannot filter all toxic chemicals.

Biological agents are neither perceptible by the senses nor detectable in real time by automatic detectors. Their effects are delayed. The particle size range of concern for biological aerosols is 1 to 5 microns, and the very high filter efficiencies necessary for these aerosols can be achieved with HEPA filtration.

Similarly, radiological agents are not perceptible by human senses and their effects are delayed. However, they can be detected in real time and are easier to decontaminate from indoor spaces than biological agents. They can be filtered at very high efficiencies with HEPA filters.

4.2 PRINCIPLES OF DESIGN FOR RISK REDUCTION RELATED TO CBR

For a building owner or manager, reducing CBR risk means reducing the CBR vulnerability of the building. There are several options for doing so that vary in effectiveness and cost. The most effective measures are those that are preventive and protective.

Preventive measures are those intended to prevent the release of a toxic agent in or into a building. Protective measures are those that impose barriers and high-efficiency filter systems between people and spaces that are or may become contaminated. A building may be considered as a system of barriers. Protective measures can be achieved by improving the building's filtration system, making the barrier system more complete, and applying pressures with fans to overcome the natural pressures of wind and buoyancy acting on air leakage paths.

There are two types of protective measures: passive (continuously protective) and active (initiated upon determining that a hazard exists or is imminent).

The nature of the CBR threat to a specific facility determines the strategy for applying preventive and protective measures. A building for which the threat, vulnerability, and asset value/consequence are considered high requires a high level of protection. If the combination of threat, vulnerability, and asset value/consequence is low, a low level of protection is appropriate. If the primary threat is an indoor or air-intake release, the greatest benefit is derived from physical security enhancements. Enhanced filtration of recirculated air is also beneficial. If the primary threat is an outdoor release, enhanced filtration of the ventilation air and/or enhanced safe rooms are most beneficial for reducing risk.

4.3 PRIORITIZATION OF CBR VULNERABILITIES: INCREMENTAL IMPROVEMENTS

There are several improvements that can protect building occupants from a CBR release or prevent a release from occurring inside or directly into a building. However, not all measures are effective against all types of agents and against all delivery methods. Systems involving air-filtration and pressurization are the most effective, and they provide secondary, but significant, benefits of better indoor air quality. They are also most expensive in terms of initial cost, operating cost, and maintenance cost.

There are seven distinct levels of CBR protection for buildings. These levels are listed below in general order of cost. Each succeeding level involves increased cost and provides greater protection for occupants and the building. Each level provides additional protection to the one preceding it, if the threat, vulnerability, and criticality so indicate. Seven options for CBR Protection include:

1. Operational measures and expedient protection

2. Enhanced physical security

3. Enhanced sheltering in place

4. Aerosol filtration, medium level
5. Gas-phase filtration, medium level
6. Aerosol filtration, high level
7. Gas-phase filtration, high level

4.3.1 LEVEL 1, OPERATIONAL MEASURES AND EXPEDIENT PROTECTION

Level 1 consists of basic, low-cost preparations for reducing the effects of a CBR attack. These are primarily operational measures and require no modifications to the building or special equipment. These operational measures involve developing procedures (active measures) for responding to a release of toxic agent, including:

- Expedient sheltering in place
  - Designating safe rooms: interior rooms with a low air exchange rate
  - Identifying switches for air handling units and fans for deactivation
  - Defining procedures and responsibilities for sheltering and for purging the building after plume passage
  - Establishing a building-wide notification system
  - Familiarizing building occupants with procedures and responsibilities
- Evacuation
- Purging
- Using escape respirators

4.3.2 LEVEL 2, ENHANCED PHYSICAL SECURITY

Level 2 measures focus on preventing the internal or air-intake release of agents. Incorporating building modifications or installing security equipment may include:

- Securing air intakes, mechanical rooms, and HVAC plenums against unauthorized access

- Performing entry inspections
- Installing and monitoring video surveillance equipment
- Instituting mail screening procedures
- Maintaining operational security to building plans and signage
- Applying mechanical and architectural isolation of lobby, mailroom, cloakroom, and loading docks

4.3.3 LEVEL 3, ENHANCED SHELTERING IN PLACE

Level 3 includes modifications to the building to make emergency protective actions more effective and to isolate zones in which indoor releases are most likely to occur. Modifications include:

- Installing single-switch control of fans for sheltering and purging
- Sealing the envelope of the building and selected safe room(s)
- Installing automatic dampers for outside air intakes and exhaust fans
- Implementing a public address system to achieve rapid implementation of emergency actions
- Isolating mechanical spaces that require large volumes of outside air by mechanical and architectural means
- Installing separate fans and air streams for ventilation and recirculation, as well as cooling and heating of safe rooms
- Installing recirculation filter units in safe rooms

4.3.4 LEVEL 4, AEROSOL FILTRATION, MEDIUM LEVEL

Level 4 is the first of four levels involving improved air filtration. It is the least costly of the four levels of filtration and includes only aerosol filtration and the use of existing air-handling units that filter mixed air (both ventilation air and return air) with the same filters. Aerosol filtration provides protection against biological agents, radiological agents, and most irritants. Level 4 may be applied to selected zones only or to the entire building (with the exception of mechanical spaces requiring large volumes of outdoor air). It provides benefits against both outdoor and indoor releases and requires:

- Sealing filter frames to minimize bypass
- Installing filters of greater depth/surface area and higher Minimum Efficiency Rating Value (MERV) rating, such as MERV 14, 15, or 16 mini-pleats
- Operating at outdoor air fractions that produce positive internal pressures of approximately 0.1 to 0.2 inch, water gauge

4.3.5 LEVEL 5, GAS-PHASE FILTRATION, MEDIUM LEVEL

Level 5 expands filtration capability in air handling units to include gas adsorbers, which are the filters needed to remove chemical vapors and gases. Using indoor-air-quality type adsorption systems that have relatively low pressure drops produces initial removal efficiencies of about 99 percent for physically adsorbed (low vapor pressure) agents and provides about 1 year service life. Filtration of chemicals of high vapor pressure is poor. This type of filtration may be applied to the entire building (except for mechanical spaces requiring large volumes of outdoor air) or to selected zones. It provides protective benefits against both outdoor and indoor releases and requires:

- Indoor-air-quality type, low resistance adsorbers that may necessitate substantial modification to air handling units
- Operating at outdoor air fractions that produce positive internal pressures of approximately 0.1 to 0.2 inch, water gauge
- Vestibules or revolving doors for highly protected zones

4.3.6 LEVEL 6, AEROSOL FILTRATION, HIGH LEVEL

Level 6 increases the level of protection against an outdoor release of toxic aerosols substantially over Level 4, but it does not provide any benefits over Level 4 against an indoor release. Level 6 requires the installation of makeup-air/ventilation units with HEPA filters. This may be applied to the entire building or selected zones. It involves:

- Installing ventilation/makeup-air units with HEPA filtration for each zone to be protected

- Vestibules or revolving doors for highly protected zones

- Operating at outdoor air fractions that produce positive internal pressures of approximately 0.1 to 0.2 inch, water gauge

4.3.7 LEVEL 7, GAS-PHASE FILTRATION, HIGH LEVEL

Level 7 involves the installation of high-efficiency gas adsorbers in ventilation/makeup air units serving protected zones. It expands the protective capability to toxic gases and vapors in addition to the aerosol capability of Level 6. Its cost is relatively high, and costs vary with the tightness of the envelope being pressurized. It provides the highest, most complete level of protection against an outdoor release and may be applied to the entire building or selected zones. It involves:

- Installing ventilation/makeup air units with high efficiency gas adsorbers as well as HEPA filters for each zone protected

- Vestibules and revolving doors for the protected zones

- Operating at outdoor air fractions that produce positive internal pressures of approximately 0.1 to 0.2 inch, water gauge.

4.4 DESIGN GUIDANCE FOR CBR PROTECTIVE LEVELS

The following sections contain detailed descriptions and discussions of the seven levels summarized above.

4.4.1 LEVEL 1, OPERATIONAL MEASURES AND EXPEDIENT PROTECTION

4.4.1.1 Scope and Capabilities

This basic level of protection is achieved by preparing emergency plans and procedures, then familiarizing building occupants with these plans

SUMMARY OF CAPABILITIES FOR LEVEL 1

Sheltering in place provides a low level of protection from **chemical agents** released outdoors. Evacuation and purging (when the nature of the release is known) provide low-level protection in response to indoor releases.

Operational measures and expedient protection are not generally practical for **biological agents** because biological agents cannot be detected in real time.

Operational measures and expedient protection also apply to **radiological agents**, but automatic detectors (e.g., radiac meters) are likely to be necessary.

and procedures for responding to a toxic-agent release. These plans and procedures cover:

- Expedient sheltering in place
- Purging
- Evacuating
- Using escape respirators

Each of these is an active measure; that is, it is initiated only when a hazard is present or known to be imminent. Active measures are most practical against chemical agents because chemical agents can be immediately detected, either by their warning properties (particularly odor), automatic detectors, or visible/audible signs of a release. Biological agents are not detectable in real time; therefore, these measures are not expected to apply for biological agents unless there is forewarning of some kind provided by those who are releasing, transporting, or storing the agent.

Sheltering in place is employed mainly for outdoor releases, evacuation mainly for indoor releases, and escape respirators for either indoor or outdoor releases.

4.4.1.2 Methods and Requirements

Sheltering in Place

Some content addressing protective actions in this section was originally published in *Protecting Buildings and their Occupants from Airborne Hazards,* U.S. Army Corps of Engineers, October 2001.

For maximum protection, sheltering in place requires two actions to temporarily change a building's indoor-outdoor air exchange rate. The first is to reduce the air-exchange rate before contaminated air begins to enter the building. This involves shutting off all fans that promote the exchange of air between indoors and outdoors, closing all exterior doors and windows, and shutting off elevators.

The second action is to increase the air-exchange rate after the outdoor hazard has dissipated. This is necessary because even a tightly sealed building will not fully prevent contaminated air from entering. However, outdoor air will enter more slowly, and once the external hazard has passed, the building will release the contaminated air slowly

The advantage of sheltering in place is that it can be implemented rapidly. The disadvantage is that its protection is variable and diminishes with the duration of the hazard. The amount of protection varies with the building air exchange rate, the duration of exposure, and the period of occupancy after the hazardous condition has passed.

Sheltering can be employed as a precautionary measure if there is an impending release (e.g., a tanker truck crash involving a fire that releases toxic material, a non-windward release when winds shift, or a release at a great distance from the building). Sheltering is not appropriate for protecting people when the duration of exposure to an outdoor hazard is long and continuous, i.e., for several hours.

The need to shelter in place may be indicated by (1) visible or audible signs of release of agent, (2) information from authorities that there has been a release in the area, (3) observed symptoms of chemical-agent exposure in people outside the building, or (4) automatic detectors, if available, sampling air outside the building or outside air as it is drawn into the building.

One option for sheltering is to use designated rooms or safe rooms, if they are better sealed than the building as a whole and/or the location of the room is less subject to wind pressures or buoyancy pressures that induce infiltration. Safe rooms may also be located in the building on the side opposite a likely source (e.g., a nearby chemical storage facility or railroad line). The safe rooms must be of a number and capacity to accommodate all building occupants and visitors. Generally, safe rooms require a minimum of 5 square feet per person, with 10 square feet per person preferred.

Using a sealed interior room within a sealed building provides greater protection than a sealed building by itself. A sealed interior room has greater resistance to infiltration flow driven by wind and buoyancy. However, use of designated safe rooms is not essential. In many cases, office buildings do not have sufficient space in interior rooms for sheltering all building occupants.

To be effective in large commercial buildings, sheltering in place requires planning and preparation. All exterior doors must be secured and all air handling units and exhaust fans must be turned off. Procedures for a sheltering plan, therefore, should include:

- Identifying all air handling units, fans, and the switches needed to deactivate them
- Identifying procedures for purging if an indoor release occurs, such as opening doors and windows; turning on smoke fans, air handlers, and exhaust fans that were turned off to shelter; and setting air-handlers on maximum outdoor air
- Designating safe rooms (see Figure 4-1), interior rooms having a lower air exchange rate that may provide a higher level of passive protection
- Establishing a building-wide notification system
- Familiarizing occupants with the procedures and responsibilities for sheltering in place

Figure 4-1: Signage designating safe room.

Although sheltering is for protection against an external release, sheltering in place on one or more floors of a multi-story building after an internal release has occurred on a single floor is also possible, though more complex. Under such conditions, stairwells must be isolated by closed fire doors, elevators must not be used, and clear evacuation routes must remain open in case evacuation becomes necessary. Escape respirators may be needed if the only evacuation routes are through contaminated areas.

Purging

Emergency actions for purging a building and reducing occupants' exposure include turning on a building's ventilation fans and smoke-purge fans and increasing air-handling units' outdoor air fraction to nominal 100 percent. Purging is useful primarily when the agent is known, the source of the agent is indoors, and as the final step in sheltering in place. The ventilation system and smoke purge fans can also be used to purge the building after an outdoor hazard has dissipated and it has been confirmed that the agent is no longer present near the building.

The location of the source and the time of the release should be carefully considered when purging. The source of agent must be inside the building; if not, purging should not be attempted. If the hazardous material has been identified before release or immediately upon release, purging should not be employed, as it may spread the hazardous material throughout the building or zone. In this case, all air-handling units should be turned off to isolate the hazard while evacuating or temporarily sheltering in place.

Evacuating

Evacuating is the most common protective action when there is an airborne hazard in a building. In most cases, existing plans for fire evacuation apply. Though evacuating is the simplest and most reliable action, it may not be the best action for an outdoor release, particularly one that is widespread. Determining whether the source of the agent is indoors or outdoors is an important consideration in a non-fire evacuation.

If the source is outdoors, and the agent has infiltrated the building, evacuation is not the safest action (unless the source has dissipated), and the use of respirators is appropriate. Sheltering in place may also be employed, but generally should not be used once the hazardous material has entered the building. Evacuation routes may also be hazardous if they take people through contaminated areas as they leave the building.

Alternate routes that do not pass through the main lobby are best. For multi-story buildings, the elevators should be avoided because elevator movement promotes the exchange of air between and among floors. Assembly points should be designated outside the building so people can be accounted for or be given additional instructions.

Using Escape Respirators

Several models of universal-fit escape respirators have been developed for short-duration escape-only protection against chemical-warfare agents, aerosols (including biological agents), and some of the toxic industrial chemicals (see Figure 4-2). The National Institute for Occupational Safety and Health has a certification process for such respirators. Most of these respirators have their protective seals at the neck, rather than around the face, and consequently do not require special fitting techniques or multiple sizes to fit a large portion of the adult population. Training is required to use the masks properly. Depending on mask design, the wearer breathes through a mouth bit or uses straps to tighten a nose cup around the nose and mouth.

The protective capability and shelf life of these masks vary with the design. The filter units of the masks contain both HEPA filters and packed carbon adsorbers, so they will remove chemical and biological aerosols, as well as chemical vapors and gases. Although the carbon filters are designed to filter a broad range of toxic chemicals, they cannot filter all chemicals. For example, the filters of escape masks are not effective against some chemicals of high vapor pressure. Unless they have a special filter, they provide no protection against the carbon monoxide that is produced in fires. Other escape hoods are available that employ compressed oxygen cylinders, rather than air filters, to provide eye and respiratory protection for short periods that vary with the intensity of the activity (i.e., walking, sitting, and climbing/descending stairs).

Plans for training, fitting, storing, and record retention procedures should be established for escape masks and respirators.

Figure 4-2: Escape respirators.

4.4.1.3 Cost Considerations

Costs of Expedient Sheltering In Place

The initial costs of establishing a basic sheltering-in-place capability are small where space is available. These costs are associated with:

- Conducting a survey to identify safe rooms
- Defining, printing, and distributing the sheltering procedures and familiarizing the building occupants with these procedures
- Assigning responsibilities for: closing doors, turning building fans off/on, and acting as safe room monitors in an emergency
- Creating signage designating the safe room and providing instructions for the occupants
- Keeping a supply of bottled drinking water in each safe room

Operating and maintenance costs are those associated with periodic training and exercises, such as an annual sheltering drill, and replenishing supplies in the safe rooms.

Costs of Escape Respirators

The initial costs of employing escape respirators that meet requirements developed by the U.S. Army and/or the National Institute of Occupational Safety and Health include:

- Purchasing respirators (approximate unit cost ranges from $100 to $300). This may include the purchase of respirators for visitors and new employees.
- Initial training in use of the respirators.
- Establishing an inventory system for the respirators that addresses serviceability checks and shelf life.

The operating and maintenance costs of escape respirators include:

- Replacement costs for respirators or respirator filters. Air-purifying type respirators require replacement every 4 to 5 years. Self-contained breathing apparatuses have a shelf life of 10 years.

- Maintaining an inventory system, conducting refresher training, reissuing serviceable unused respirators, and ordering and issuing replacement respirators or filters. Cost data from one Federal facility show this cost to be roughly 10 percent of the respirator costs per year.

4.4.2 LEVEL 2, PHYSICAL SECURITY

4.4.2.1 Scope and Capabilities

SUMMARY OF CAPABILITIES FOR LEVEL 2

Level 2 consists of physical security measures, preventive or deterrent measures that apply to indoor releases or outdoor releases close to the building.

These measures apply to all toxic agents—**chemical, biological,** and **radiological agents**—although detectability makes them most practical for chemical agents.

The purpose of the physical security measures applied in this level is to prevent the release of an agent from a point inside the building or through a penetration in the building shell from a point near the building.

These physical security measures, which also provide benefit against other criminal acts, include five measures as described in 4.4.2.2 below.

Physical security measures are preventive measures; they serve to deter potential attackers and to prevent the release of agent in or into the building. They are effective only within the building and/or its secure perimeter; they apply to indoor releases and outdoor releases near the building.

Among the security measures presented below, only the entry inspection requires the capability to detect toxic agents. Because of technical challenges in detecting and reliably identifying agents, entry inspection is most practical for chemical agents and least practical for biological agents.

4.4.2.2 Methods and Requirements

Securing Air Intakes

Securing air intakes is the highest priority physical security measure (see Figure 4-3). There are, however, several degrees of vulnerability for air intakes. Generally, the more difficult an intake is to access for surreptitious insertion of a toxic agent, the lower its vulnerability. Elevating intakes is the best approach to decreasing vulnerability. In retrofit, however, doing so can be expensive and require architectural

Figure 4-3: Typical air intakes.

changes that may not be aesthetically acceptable. There are less expensive, less effective measures that can be taken to reduce intake vulnerability, such as installation of security fencing and surveillance cameras. Whether an intake should be secured depends on its vulnerability and the level of threat to the building.

Securing Mechanical Rooms and HVAC Plenums

Securing mechanical rooms is a relatively inexpensive means of denying access to the HVAC system (except for the outside air intakes). Unsecured mechanical rooms present a vulnerability similar to but lower than unsecured outside air intakes. In most cases, mechanical rooms are accessed from inside the building; therefore, the routes of access are subject to the physical security of the building.

HVAC ceiling plenums present an accessible pathway to the air-handling units, in which a dissemination device could be concealed by lifting a drop-ceiling tile. Plenum return pathways are not present in buildings with ducted returns and cannot be secured in buildings with hallway returns. Securing the ceiling plenum is impractical in most applications because access to the ceiling plenum must be retained for maintenance purposes.

Performing Entry Inspections

Adding entry inspections to prevent containers of toxic agents from being brought into a building is practical only if security guards control access to the building. Entry inspections have varying degrees of effectiveness. They can be effective for both deterrence and detection. Detecting toxic agents in containers is difficult, however, as there is no practical technology for rapid, non-intrusive detection/identification of toxic agents. Current methods of detection are based on the type of container (e.g., pepper spray devices) or on quantities of specific chemicals detected on exposed surfaces.

Performing entry inspections in a lobby that is isolated architecturally and mechanically from the rest of the building is best. Such isolation should involve measures described in 4.4.3.2. In some cases, performing entry screening in a separate building (i.e., a visitors center) is more efficient and effective than modifying a lobby for isolation. Similarly, it may cost less to receive, inspect, and sort mail and packages in a separate building.

Employing Video Surveillance

The principles of deterrence and detection are also applied in the use of video surveillance equipment. For detection to be effective in preventing or mitigating the effects of a release, images from the cameras must be monitored continuously in real time. For deterrence, the surveillance must be overt rather than covert. Because of privacy concerns, overt surveillance is most commonly employed in office buildings.

Generally, surveillance cameras should be placed in common areas that are not within the normal view of security personnel. Indoors, these areas may include hallways, cloakrooms, and obscure parts of the lobby. Outdoors, suitable placement may include unsecured air intakes and areas where vehicles or pedestrians may release an agent that would be transported into the building.

Other Security Considerations

Building plans may contain information relevant to CBR vulnerabilities. For this reason, access to drawings and specifications should be restricted.

4.4.2.3 Cost Considerations

The cost of installing security equipment varies substantially with the number of surveillance cameras, resolution and features of cameras, and monitors and recording equipment.

4.4.3 LEVEL 3, ENHANCED SAFE ROOMS AND ISOLATED ZONES

4.4.3.1 Scope and Capabilities

Level 3 CBR protection involves increased protection against indoor releases. This level includes architectural and mechanical modifications to designated safe room(s) to increase the protection the safe room can provide, and to zones of concern, such as the mailroom and lobby, to isolate them from the rest of the building. The mailroom is a primary zone of concern, and the lobby is a zone of concern for access-controlled buildings. Isolating zones of concern is a passive measure that prevents the transport of airborne agents to other spaces of the building.

SUMMARY OF CAPABILITIES FOR LEVEL 3

Level 3 mitigates indoor releases. It applies to all types of agents: **chemical, biological,** and **radiological**.

These measures prevent an agent released in a lobby or mailroom from migrating to other parts of the building and require access control and some level of entry screening.

For enhanced sheltering in place, the protective capabilities described in level 1 apply.

4.4.3.2 Methods

Safe Room Enhancements

There are three classes of safe room, as defined by U.S. Army documents on CBR collective protection (USACE, 2001). These classes provide three levels of protection, with Class I being the most protective.

Class I safe rooms are ventilated and pressurized by air filtered at high efficiency.

Class II safe rooms have air filtration with either no ventilation or a ventilation rate that produces little or no overpressure.

Class III safe rooms are unventilated and have no air-filtration equipment. These safe rooms apply what is commonly referred to as sheltering in place.

The features listed below facilitate rapid transition to sheltering mode and improve the level of protection a CBR safe room provides. These apply mainly to Class II and III safe rooms, but some apply to Class I. The design of Class I (pressurized) safe rooms is covered under Level 7.

For commercial buildings, these enhancements are as follows:

- Single-switch, rapid-shutdown capability for all fans that induce indoor-outdoor air exchange (See Figure 4-4). This includes shutdown capability for ventilation fans, exhaust fans, and air-handling units that draw outside air.

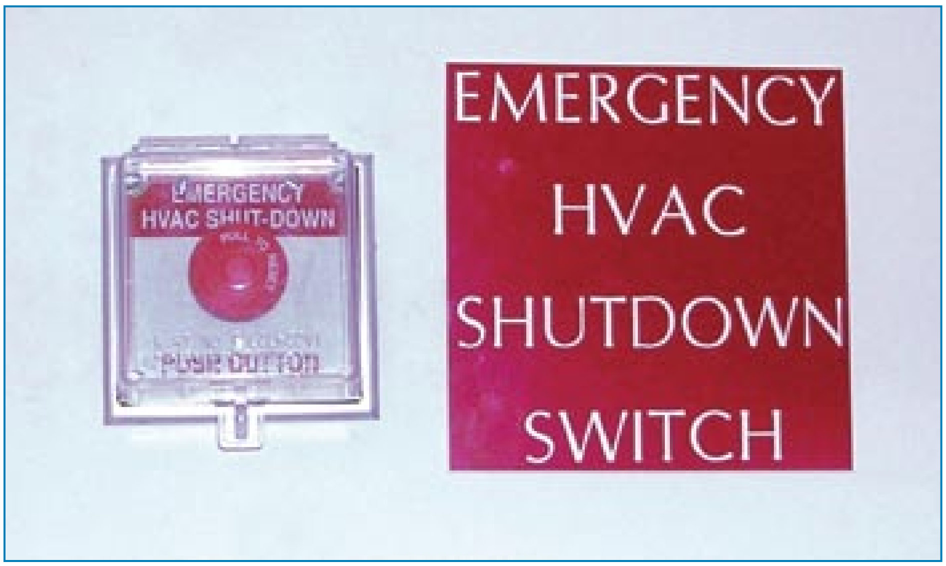

Figure 4-4: A single switch for stopping HVAC fans.

- Sealing measures. The level of protection varies with the tightness of the building in its sheltering configuration; the lower the air exchange rate, the higher the level of protection.

- A public-address system to rapidly instruct all people in the building to shelter in place (i.e., not to exit the building or open exterior doors). A broadcast voice system is preferable to a tone-alert, ring-down, or computer-screen message system because it is the most rapid and reliable.

- Dampers for outside air intakes and exhaust fans. Dampers should be automatic and interlocked with the fan operation and must be maintained in good working order.

Typical dampers are not effective enough to allow heating and air conditioning in the safe room while in the sheltering mode. Safe use of an air-handling unit serving a CBR safe room requires a recirculation fan separate from the makeup air fan. Cooling or heating in the safe room in the sheltering mode can be safely accomplished with separate ventilation and recirculation fans, when the damper for the ventilation fan is closed. A system with separate fans eliminates the potential for internally induced infiltration that typically occurs with an air-handling unit (single fan and damper) in the full recirculation mode.

Filtering recirculated air in a safe room increases the protection level of the safe room from Class III to Class II. Some recirculation filter units have substantial adsorbers as well as high-efficiency particulate air filters and are suitable for enhanced sheltering in place (See Figure 4-5). To improve the safe room's protection against chemical agents, the filter unit must have a substantial gas adsorber. The adsorber removes most chemical agents, while the high-efficiency particulate filter, found in most recirculation filter units, removes biological agents and other aerosols such as radioactive dust, tear gas, and pepper spray. While recirculation filters have the capability of removing biological agents, it is unlikely that the safe room would be used in the case of a biological release due to limitations in detection capability for biological agents.

Figure 4-5: Two recirculation filter units.

Isolating the Lobby and Mail Room

The lobby and mailroom are two spaces in an office building in which a toxic agent release would be most likely to occur. Isolating these spaces architecturally and mechanically reduces the probability that large portions of the building will become contaminated by an indoor release. The probability of a lobby release is higher if the building is access-controlled and the lobby is open to the public.

Isolating these spaces from the rest of the building may require both architectural and mechanical changes, including:

- Full-height walls
- A dedicated air handling unit (serving only the space) if an all-air HVAC system is used
- An exhaust fan or system balancing to maintaining the space at a negative pressure relative to the rest of the building
- Doors into and out of the lobby that are normally closed (The frequency of entries and exits determines whether vestibules or revolving doors are also required.)

4.4.3.3 Cost Considerations

Initial costs vary widely, as lobbies generally require architectural changes to place a barrier and doorway between the lobby and adjoining spaces. Mechanical changes would require a separate air-handling unit for the space.

4.4.4 LEVEL 4, AEROSOL FILTRATION, MEDIUM LEVEL

4.4.4.1 Scope and Capabilities

This is the first of four levels involving improved air filtration. Among the four, it is the simplest to apply and requires the least cost and space. Any improved air filtration requires a licensed mechanical contractor to ensure effective installation and prevent adverse effects on ventilation rates and HVAC system operation.

Level 4 involves aerosol filtration only in the existing air-handling units and provides a medium level of protection because the filters are less efficient than HEPA filters. Also, existing air-handling units typically allow substantial volumes of air to bypass the filters. This bypass occurs not only at the filter-holding frames but also at leakage paths in the air-handling unit cabinet under negative pressure.

SUMMARY OF CAPABILITIES FOR LEVEL 4

Level 4 improves the protection against **biological and radiological agents** and certain irritants in aerosol form, such as tear gas and pepper spray.

For these agents, this provides a medium level of protection against outdoor releases and a low level of protection against indoor releases.

This level adds no capability to protect against **chemical agents**. At this level, sheltering in place provides capability for protecting against chemical warfare agents and toxic industrial chemicals (TICs).

4.4.4.2 Methods and Requirements

This increased level of protection for aerosols requires:

- Installing filters of higher MERV within available space and within resistance limitations of the air-handling unit fan. This is most easily accomplished by installing filters of mini-pleat configuration having greater filter depth and therefore, greater surface area.

- Sealing filters to their retaining frames to minimize bypass, and sealing leakage paths on the air-handling unit cabinet between the filter frames and the fan.

- Operating at outdoor air fractions that produce a positive internal pressure in the building.

The details of sealing frames vary from installation to installation. Generally, front-access filters provide much better potential for reducing bypass than do side-access filters, although there are side-access housings available with locking mechanisms to ensure a good filter seal. Pressurization levels are the same as those discussed for Levels 6 and 7.

4.4.4.3 Cost Considerations

The costs of modifications to the filter holding frames vary with the type and condition of the air-handling unit.

Additional resistance to flow in terms of pressure drop may result in increased operating costs, which are likely to be offset by additional service life resulting from greater surface area.

Costs of replacement filters will increase, as will the labor to change filters, re-establish effective seals, and dispose of hazardous wastes that are characteristic for higher efficiency filters.

4.4.5 LEVEL 5, GAS-PHASE FILTRATION, MEDIUM LEVEL

4.4.5.1 Scope and Capabilities

SUMMARY OF CAPABILITIES FOR LEVEL 5

Level 5 applies a medium level of protection against **chemical warfare agents** and against some TICs released outdoors.

It provides a low level of protection against indoor releases of these chemical agents.

The filtering capability for chemicals of higher vapor pressure is less than that of Level 7.

This level provides no additional capability for **biological or radiological agents** beyond Level 4.

The second level of filtration involves the addition of adsorbers to the HVAC system to filter chemical agents from recirculated air and ventilation air. This level produces substantial protection against a chemical release either indoors or outdoors; however, it provides a lower level of protection against an outdoor release than Level 7.

Adsorbers for this application are commercially available and commonly used in buildings having special indoor-air-quality requirements. As such, the adsorbers have a relatively low resistance (pressure drop of around 0.5 to 1 inch, water gauge) and consequently, a much lower efficiency (initially about 99 percent) and capacity than adsorbers made to the higher standards of military or Department of Energy specifications.

These adsorbers do not filter agents of higher vapor pressure as well as military adsorbers do. Typically, they have coarse granular carbon trays of 1-inch depth in a V-bed configuration. The units typically have an initial bypass of at least 1 percent. There are also adsorbers made of multiple layers of pleated, carbon-loaded, non-woven material (see Figure 4-6).

This capability is best attained with installation of adsorbers in an air-handling unit or ducted in line. A similar capability can be attained with free-standing, floor-mounted units or ceiling-mounted units; however, these are less practical in most large commercial buildings in that several units may be necessary in each room to provide performance equivalent to the units ducted in line or mounted in the air-handling unit.

Service life of these adsorbers is typically 12 to 18 months; however, efficiency diminishes with time in service, to relatively low values within a year, reducing the protection provided to low levels later in the service

Figure 4-6: 9,000-cfm filter unit incorporating pleated adsorbers.

life period. Manufacturers of the adsorbers provide surveillance testing to help determine the frequency of filter replacement.

4.4.5.2 Methods and Requirements

Adsorber units can be installed by adding an adsorber section (approximately 3 feet long) to an air-handling unit, or by adding an in-line filter unit in the supply duct. Upgrading the air-handling unit fan/motor may be necessary to accommodate the additional airflow resistance of the adsorbers.

There are two types of adsorbers, those with granular carbon beds and those with carbon pleats consisting of non-woven material loaded with fine-mesh carbon granules. Comparison of performance between these two types of adsorbers can be made on a carbon-per-cubic feet per minute (cfm) basis (usually this is in the range of 0.05 to 0.1 pound per cfm for substantial efficiency and capacity).

Multi-panel housings in which removable flat panels form V-bed configurations generally have greater bypass than V-bed cells or pleated cartridges.

4.4.5.3 Cost Considerations

The installation costs for adsorber units are about $0.50 per cfm. With a one-year service life, filter replacement costs are about $0.25 per cfm per year. Additional operating energy costs are about one fourth the maintenance costs due to the pressure drop of the adsorbers (0.75 inch of water gauge).

4.4.6 LEVEL 6, AEROSOL FILTRATION, HIGH LEVEL

4.4.6.1 Scope and Capabilities

SUMMARY OF CAPABILITIES FOR LEVEL 6

For **biological or radiological agents**, Level 6 provides the highest possible level of protection against outdoor releases.

Against an indoor release of **biological or radiological agents**, this level does not improve upon the protection Level 4 provides.

Except for irritant aerosols, this provides no additional capability for **chemical agents** beyond sheltering in place (Levels 2 and 3) or the adsorbers of Level 5.

This level is the first of two that involve very high efficiency filtering of ventilation air separately from recirculation air. This level is for aerosol filtration only and is to be applied in a continuously operating system, rather than activated upon detection, because biological agents are not detectable in real time.

4.4.6.2 Methods and Requirements

This level involves the installation of a makeup-air unit with HEPA filters and an effective sealing system to prevent filter bypass. The makeup-air unit requires heating and cooling coils to temper the air introduced into the building before it is further conditioned by the air-handling units.

An ultraviolet germicidal irradiation (UVGI) system of certified performance could be used in place of the HEPA filter for disinfection of air as it enters the building; however, such systems also require mechanical filtration for removal of other aerosols (and to keep lamp and reflector surfaces clean). Although there are several UVGI systems on the market for use in air-handling units, most do not have the capability for high-efficiency disinfection of biological threat agents in air. Some systems are intended for surface disinfection, killing mold, bacteria, and fungi on cooling coils or drain pans. There is currently no certification process for UVGI systems for protection against bio-agent attack.

Less space is required for Level 6 makeup-air units than Level 7, which requires both HEPA filters and high-efficiency adsorbers. Sizing of the filtration system in terms of airflow capacity is determined by the building's leakage rate and the square footage of the protected space. With normal building construction techniques, leakage is less than optimum for pressurization of the building. Desired pressure levels in low-rise buildings are 0.1 to 0.2 inch, water gauge, and greater in high-rise buildings. Pressurizing a building to these levels usually takes substantially more ventilation air than is supplied for health and comfort requirements. Table 4-1, below, shows the flow rate of air required per square foot of floor area for a 0.1-inch, water gauge pressure.

The airflow required for pressurization can be determined by fan-pressurization testing, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) tables (ASHRAE, 2004), and tables based on previous fan-pressurization tests provided by the manufacturer.

Table 4-1: Estimated Makeup Airflow Rate per Square Foot (Floor Area) to Achieve an Overpressure of 0.1 Inch, Water Gage

Type of Construction	Airflow Rate (cfm per sq ft floor area)
Very Tight: 26-inch thick concrete walls and roof with no windows	0.04
Tight: 12-inch thick concrete or block walls and roof with tight windows and multiple sealed penetrations	0.20
Typical: 12-inch thick concrete or block walls with gypsum wall board ceilings or composition roof and multiple sealed penetrations	0.50
Loose: Wood-frame construction without special sealing measures	1.00

4.4.6.3 Cost Considerations

This level is relatively high in cost because it requires pressurization of the building or selected spaces to ensure that all exchange of indoor and outdoor air occurs through the filters. Pressurizing buildings typically requires substantial increases in the rate of ventilation air flow, which leads to increased heating and cooling costs.

4.4.7 LEVEL 7, GAS-PHASE FILTRATION, HIGH LEVEL

4.4.7.1 Scope and Capabilities

As with Level 6, this level also involves filtering the ventilation air separately from recirculation air at very high efficiency. Level 7 involves

SUMMARY OF CAPABILITIES FOR LEVEL 7

For chemical agents, Level 7 provides a very high level of protection for filterable chemicals released outdoors.

This level does not increase the protection against biological or radiological agents beyond that of Level 6.

Against an indoor release, this level does not provide benefit beyond that of Level 5.

the installation of high-efficiency gas adsorbers to filter makeup air for pressurizing the protected zones, and thereby expands the high-level protective capability to toxic gases and vapors.

Because this level includes HEPA filtration in series with the high-efficiency adsorber it provides the highest, most complete level of protection against an outdoor release of chemical, biological, or radiological agents. However, it is limited in the filtration of some chemical agents of higher vapor pressure. Generally, chemicals of vapor pressure above 10 millimeters of mercury are filtered by chemisorption; that is, carbon is impregnated with salts of copper, silver, zinc, and molybdenum, and the gases react with these impregnants as they pass through the filter bed to form products that are innocuous or retained in the bed. However, the best broad-spectrum carbon will not filter all toxic chemicals. The addition of a special sorbent, mixed or layered in the bed, can add to the filter capability for specific gases, but increases the size and resistance of the adsorber.

Filtering only ventilation air is not effective against an indoor release. Protecting against an indoor release requires the internal filtration of Levels 4 and 5 or the physical security measures of level 2.

4.4.7.2 Methods and Requirements

Among the primary decisions in applying this level of protection is whether to protect the whole building or a relatively small selected space. This decision is usually based on cost and the need for a high level of protection.

Whole building. In pressurizing the whole building, mechanical rooms are generally excluded or divided to exclude furnaces or boilers from the protected space. In mechanical rooms containing both air-handling units and boilers, the mechanical room is partitioned so that the air-handling units are within a pressurized space and the boilers are not.

Selected space. Spaces usually selected for pressurized, high-level chemical protection are security operations centers, emergency operations centers, command and control centers, command suites, and safe rooms. A safe room with this level of protection is considered a Class I safe room (section 4.4.3).

A second decision regarding the application of Level 7 is whether to design a continuously operating system or a standby system. The latter may be applied because gas-phase filtration is for chemical agents, which can be detected in real time. Therefore, the system can be activated upon detecting a release or learning of a heightened threat level. Canister-type filter systems for use in safe rooms and home shelters are intended for standby use; these are hermetically sealed and can retain their full capability for at least 10 years. The high-efficiency filtration unit can be installed in a mechanical room, on the roof, or at grade inside secure fencing.

Three types of adsorbers commonly used are V-bed, radial-flow, and pleated, as shown in Figure 4-7. Installations of radial-flow and V-bed adsorbers are shown in Figures 4-8 and 4-9.

Figure 4-7: Three types of high-efficiency gas adsorbers commonly used (from left to right: radial-flow M98 military adsorber, V-bed adsorber, and multi-layer pleated adsorber).

Figure 4-8: Radial-flow adsorbers in multiple 1,000-cfm housings in a 16,000-cfm system serving a hospital.

Figure 4-9: A 6,000-cfm V-bed filter unit serving a 12,000 sq ft safe room.

4.4.7.3 Cost Considerations

Installing, operating, and maintaining systems for ultra-high efficiency gas adsorption is very expensive. Installing such a system costs approximately $20 to $100 per square foot.

The principal maintenance cost is the replacement of filters, the high-efficiency gas adsorbers, approximately every 3 years. This equates to a cost of $2 per year per cfm, or about $0.50 to $1.00 per square foot per year. Energy costs for such units are about one-fourth the maintenance costs.

4.5 SUMMARY

Operational Risk-Reduction Measures for CBR

The following summarizes the operational measures for CBR risk reductions:

- Develop plans, procedures, and training for sheltering in place, evacuation, and purging

- ❍ Provide CBR threat awareness and response training to building occupants
- ❍ Purchase escape hood respirators for all occupants and provide training in their use
- ❍ Secure air intakes, mechanical rooms, and HVAC plenums against unauthorized access
- ❍ Perform entry inspections at the building lobby
- ❍ Institute mail-screening procedures
- ❍ Maintain operational security for building plans and building signage

Building Upgrades for CBR

- ❍ Install single-switch control of all building fans to facilitate sheltering in place and purging
- ❍ Install a public-address system to achieve rapid implementation of emergency actions
- ❍ Apply sealing measures to tighten selected safe room(s)
- ❍ Install automatic dampers for outside air intakes and exhaust fans to facilitate sheltering in place
- ❍ Place recirculation filter units having substantial adsorbers for use in safe rooms
- ❍ For safe rooms, install a separate, isolated recirculation system for cooling and heating
- ❍ Install and monitor video-surveillance cameras
- ❍ Isolate the lobby, mailroom, cloakroom, and loading dock architecturally and mechanically
- ❍ Install filters of greater depth/surface area and higher MERV rating, such as MERV 14, 15, or 16 mini-pleats, in air-handling units and seal filters and frames to minimize bypass
- ❍ Modify air-handling units to install indoor-air-quality type, low resistance adsorbers

- Install ventilation/makeup-air units with HEPA filtration for each zone to be protected

- Install ventilation/makeup-air units with high-efficiency gas adsorbers, as well as HEPA filters for each zone protected

- Install vestibules or revolving doors for highly protected zones

- With upgraded air filtration, operate air-handling units at outdoor air fractions that produce positive pressures of approximately 0.1 to 0.2 inch, water gauge, in the building

4.6 CBR PROTECTION MEASURES

The preceding discussions of CBR threat mitigation measures can be condensed into the following list. It is presented here as an example of measures that might be generated by the FEMA 452 process and implemented using this document (FEMA 459), as discussed in Chapter 2. These measures are all included in the list that comprises the vertical axes of the matrices in Section 2.3.

Level 1, Operational Measures and Expedient Protection

- Expedient sheltering in place
    - Designating safe rooms, interior rooms having a lower air exchange rate
    - Identifying switches for all air-handling units and fans for deactivation
    - Defining procedures for sheltering and for purging the building after plume passage
    - Establishing a building-wide notification system
    - Familiarizing occupants with procedures and responsibilities

- Evacuation

- Purging

- Using escape respirators

Level 2, Enhanced Physical Security

- Secure air intakes against unauthorized access
- Secure mechanical rooms and HVAC plenums against unauthorized access
- Perform entry inspections
- Employ video surveillance equipment
- Institute mail screening procedures
- Maintain operational security to building plans and signage
- Apply mechanical and architectural isolation of lobby, mailroom, cloakroom, and loading docks

Level 3, Enhanced Sheltering In Place

- Install single-switch control of fans for sheltering and purging
- Tighten the seal for the envelope of the building and selected safe room(s)
- Install automatic dampers for outside air intakes and exhaust fans
- Implement a public address system to achieve rapid implementation of emergency actions
- Isolate mechanical spaces that require large volumes of outside air
- Install separate fans and air streams for ventilation and recirculation, as well as cooling and heating, of safe rooms
- Use recirculation filter units in safe rooms

Level 4, Aerosol Filtration, Medium Level

- Seal filter frames to minimize bypass
- Install filters of greater depth/surface area and higher MERV rating
- Operate at positive internal pressures

Level 5, Gas-Phase Filtration, Medium Level

- ❍ Install indoor-air-quality type, low-resistance adsorbers
- ❍ Operate at positive internal pressures
- ❍ Install vestibules or revolving doors for highly protected zones

Level 6, Aerosol Filtration, High Level

- ❍ Install ventilation/makeup-air units with HEPA filtration
- ❍ Install vestibules or revolving doors for highly protected zones
- ❍ Operate at positive internal pressures

Level 7, Gas-Phase Filtration, High Level

- ❍ Install ventilation/makeup-air units with high-efficiency adsorbers and HEPA filtration
- ❍ Install vestibules or revolving doors for the protected zones
- ❍ Operate at positive internal pressures

All of these measures can be implemented independently with the exception of expedient sheltering in place (Level 1).