PDHonline Course C741 (6 PDH)

Homeland Security Design and Construction

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PDH Online | PDH Center

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Homeland Security Design & Construction

Module A: Introduction and History

This Homeland Security Design Home Study Course is designed for owners; design professionals, contractors and other construction professionals who would like to improve their knowledge of security and building design issues, techniques and trends related to homeland security implications for building design and construction.

This course provides participants with an understanding of the lessons learned from recent terrorist activities and the best practices that are evolving to form the foundation of better homeland security design and construction.

The relevant topics that affect design and construction considerations regarding security issues include:

- The current issues that affect homeland security building design and construction
- The differences between homeland security and the other vulnerabilities and threats that affect security and construction
- Risk analysis from the prospective of homeland security relative to such factors as greatest threats, weakest design points, and cost versus security trade-offs
- How to determine and assess needs and requirements for homeland security
- Building into construction design a homeland defense environment
- Discovering where to find the latest in sources of goods and services
- Best practices in security and design and construction requirements for new infrastructure
- How to specify and design for homeland defense in renovations and retrofits
- The latest facts about commissioning and intrusion testing
- The techniques about operations monitoring and testing of the built homeland security measures

The course is intended to help participants improve their understanding of the problem and potential solutions for improving homeland security design and construction in our domestic and global society as complicated by the ever increasing potential of terrorism.

Why Homeland Security?

The answer to this question is obvious now based on a single catastrophic event, although there has been a trend calling for this need over the past few decades.

- We all received an extreme wake up call after the fall of the twin tower in New York City. Unfortunately, it took a horrific event to bring this topic to the forefront of building design and construction.
- Prior attempts have been made to universally wake us up through the initial bombing of the World Trade Center in 1993, Oklahoma City Murrah Building bombing, attempted destruction of our overseas embassies and properties, etc.
- We have come to the conclusion that we need to find better ways to protect occupants, assets and buildings from human aggressors.
- We are being threatened by a non-traditional means of warfare called terrorism. For the purpose of this course, we will call al of these human aggressors "terrorists" that would include disgruntled employees, criminals, vandals and terrorists.

Why are we Vulnerable?

We are vulnerable because of the incredible freedoms afforded by our Constitution, our form of government, and the history of peace in our homeland.

- Civil liberties pursuant to the Bill of Rights provides everyone, whether a citizen or terrorist, the freedom to act independently and exercise their rights if they so choose.
- Openness of society as a tenet of democracy and the freedoms that we enjoy provides haven for those that seek and choose to act in an evil manner.
- Lack of defense in terms of government or private business controls necessary to thwart or mitigate a terrorist attack.
- Our economic strength and open access by world wide markets provides an extensive array of potential targets.

The United States has the most elaborate infrastructure in the world, including:

- Federal and State government facilities
- Bridges and tunnels
- Dams
- Rail systems
- Air transportation system
- Public gathering places

Each element of our infrastructure has security vulnerabilities. Our infrastructure is vulnerable because it is sophisticated, unguarded and designed without security. In the past, this design basis comes from almost two hundred years of history without invasion or threat. Unfortunately, this design basis needs to be revised, based on today's unique challenges.

What is Homeland Security?

Homeland Security addresses the security of the United States' homeland from nontraditional and emerging threats as a primary national security mission of the United States Government. The basis under which homeland security must under take includes the following:

- It recognizes that attacks on the United States may involve weapons of mass destruction and weapons of mass disruption.
- It must guarantee that homeland security is achieved within the framework of law that protects the civil liberties and privacy of United States citizens.
- It recognizes that a comprehensive strategy, new organizational structures, responsibilities, priorities are essential to combating the terrorist threat.

National versus Homeland Security

Homeland Security is a recent defense strategy that has been developed to be separate from National Defense.

National defense addresses the protection of the United States' sovereignty against the aggressive acts of other nations.

- This traditional sense of defense results in military conflicts.
- National defense addresses our political and strategic interests on a global scale.
- National security design and building results in forts, airbases and navy yards.

Homeland Security addresses the security of the United States' homeland from nontraditional and emerging threats.

- Homeland Security responds to terrorists, criminals committing mass crimes, and catastrophic white collar crime on American soil.
- Homeland security design and building results in safe arenas, secure courtrooms and secure travel ways.

Infrastructure Implications and Innovations

- The physical assets of our country have never been protected at the levels common in other parts of the world.
- Rarely are physical measures tested to measure effectiveness.
- The cost-benefit ratio of Homeland Security has changed dramatically since 9/11.

Trends

- It is estimated that for the next ten years, terrorist tactics will become increasingly sophisticated and designed to achieve mass casualties.
- The trend away from state-supported political terrorism, and toward more diverse, free-wheeling, transnational networks, funded by non-governmental sources, will continue.
- The U.S. national infrastructure—communications, public gathering points, transportation, financial institutions, energy networks—will remain vulnerable to disruption by physical threats until the nation is prepared to

acknowledge the visual presence of defense measures, accept them financially and train in their use.

The New Paradigm

- Terrorism and mass casualty crimes are a fact of life and will not go away.
- We must coordinate infrastructure design and construction with operational, information technology and criminal response efforts.
- The entire infrastructure cannot be protected, but vulnerability can be reduced and money can be optimally spent.
- Assessing and prioritizing the threats and providing Homeland Security solutions to design and construction is our responsibility.

Key Concepts for the New Paradigm

There are new concepts central to Homeland Security that impact design and construction. These concepts are the four cornerstones of Homeland Security infrastructure development.

- Prediction - Indicators that measure vulnerability
- Detection - Physical measures that warn of actual intrusion and impending harm.
- Prevention and Deterrence - Passive and active infrastructure features that defeat, impede or contain an actual threat.
- Response - Passive and active operational measures that complement infrastructure features with response to an incident in progress.

Why Study Past Terrorist Events?

The review of past attacks can point us in the right direction toward effective homeland security design and construction. This study will provide us with the following results:

- Past events lead us to understand future vulnerabilities in design, strength of materials, and why a building is targeted.
- Past events are the fundamental test of success or failure of effective design and construction.
- Past events findings lead us to new and improved design and construction standards.
- Recall of past events keeps us from becoming complacent.

World Trade Center - 2/23/93

The World Trade Center was first targeted by Arab extremists almost ten years ago.

- On February 23, 1993, a panel truck carrying more than 1,000 pounds of explosives exploded in the north tower, leaving six people dead and over 1,000 injured, but left the towers standing.
- The explosion created a crater three stories deep in the parking garage and the lower part of the tower causing millions of dollars worth of damage.
- The terrorist strategy was horrendous:
  - Topple the taller tower of the WTC into its twin tower
  - Simultaneously release a cloud of cyanide gas into the air

- Lessons learned:

1. We cannot ignore the obvious. The WTC has always been a target, but complacency had already reasserted itself by 9/11/01.
2. The towers survived the attack due to demanding design standards and quality construction.
3. The design parameters of the WTC towers were sound.

Oklahoma City - Murrah Building Blast

On April 19, 1995, Timothy McVeigh and his accomplices bombed the Murrah Federal Building in Oklahoma City.

- The blast caused the collapse of part of the nine story building and major damage to nearby structures.
- The resulting detonation resembled that of a spherical charge of TNT weighing approximately 4,000 lbs. The actual explosive was ANFO.
- The crater was approximately 28ft in diameter and 6.8 ft in depth. The explosion center was 7 ft east and 14 ft north of column G20, a key structural member.
- Such a detonation produces an air blast wave that propagates radially from the burst point. It is characterized by an instantaneous rise to a peak value, termed incident pressure followed by a secondary, or reflective pressure.

<u>Blast analysis findings</u>

- The Murrah Building suffered damage to three structural columns and a connecting girder as a direct result of the bombing.
- Three intermediate principal columns supporting a third-floor girder failed.
- Some floor slabs were demolished.
- Floor slabs in close proximity to bomb were directly loaded and collapsed.
- The glass panels restrained by aluminum channels (glazing) offered insignificant resistance to the blast.
- Upon failure of the windows and glazing, the structural bays were filled by instant pressure from the blast and reflective pressure from below. Thus, each slab experienced a blast pressure from the exterior and upward pressure from the floor below.

<u>Lessons Learned</u>

1. The "Heartland" of America is no longer isolated from the reaction of political action groups of either the extreme left or right, domestic or foreign.

2. The Federal Response Plan did not adequately incorporate the response activities and missions of Federal law enforcement agencies.

3. State and local plans and exercises need to be changed to incorporate response forces working in and around a large crime scene.

4. Local and state emergency plans must address the local situation, and must be coordinated and integrated with the U.S., Regional and Federal Response Plans.

5. A need exists for National and regional integrated training among government and emergency management agencies.

6. The General Services Administration (GSA) reported that federal building construction since the bombing of Oklahoma City's Murrah Building requires an additional 5 to 10 percent premium in added security costs.

Bombings of US Embassies

A group of coordinated suicide bombings hit our embassies at Nariobi, Kenya and Dar es Salaan, Tanzania on August 7, 1998.

- Both structures withstood collapse from bombings
- However the structures were rendered unusable
- Several adjacent buildings were severely damaged or destroyed

<u>Lessons learned</u>

1. Terrorists intended to destroy the embassies, kill US government employees and others and negatively affect the political climate.
2. Security systems and procedures for physical security at the embassies as a general matter met and, in some cases, exceeded the systems and procedures prescribed by the U.S. Department of State.
3. The Department of State does not fully implement its security standards; nor do other federal agencies.
4. The general rule is to implement design standards only “to the maximum extent feasible,” rather than to perform a risk assessment and design accordingly.

5. Security procedures were, for the most part, properly implemented, but design was inadequate.

6. At both embassies, the suicide bomber failed in his attempt to penetrate the embassy's outer perimeter.

7. Building considerations should include improving:

    - Location - less dense area of city
    - Security - greater distances from first level security ring to building
    - Longer range camera surveillance up to the facility targeting risk targets such as trucks, vans and suspicious vehicles

World Trade Center - 9/11 Assessment

On September 11, 2001, Al Quaeda terrorists took over two jetliners and rammed them into the WTC, killing thousands and destroying two of America's symbols of pride and economic strength.

An analysis by an ASCE/FEMA team of 25 of the nation's leading structural and fire protection engineers stated that the WTC could have remained standing indefinitely if fire had not overwhelmed the weakened structures.

Significant findings –

- Much of the jet fuel burned off in fireballs outside the building.
- The jet fuel ignited other combustible materials simultaneously over several floors.
- The WTC buildings sustained no significant structural damage, but instead became the first protected steel structures to collapse solely due to fire.
- Contributing to the collapse was failure at connections between the structural steel beams, most apparent in Building 5

In conclusion, the actual cause of the collapse was the consequence of prolonged heating of the steel columns. Heating lowered the yield strength and caused viscoplastic buckling (creep) of the columns of the framed tube along the perimeter of the tower and of the columns in the building core.

Lessons Learned

1. Buildings should be designed with sturdy, redundant structural support.

2. Fireproofing needs to adhere under impact and fire-induced steel to provide the intended protection.

3. The connecting structural elements (nuts, rivets and plates) need to be analyzed to better understand how they fare under sudden impact and fire.

4. When sprinkler systems are a critical part of a building's fire protection system, the water supply should be reliable and redundant.

5. Stairwells must be evaluated for strength and multiple alternate routes of escape in order to provide safe and clear evacuation routes when the building is damaged. Rally points must be provided for evacuees.

6. Fire protection ratings and safety factors for structural transfer systems should be evaluated for their adequacy relative to the role of transfer systems in building stability.

7. The final conclusion was that there was no need for code changes. Existing codes are adequate.

The Pentagon Terrorist Attack

- The structural design of the Pentagon minimized or compartmentalized the potential for horrific damage due to its ring structural design.

- Several of the newly designed additions helped to prevent massive casualties due to:

    - Blast proof windows
    - Window glazing

Hart Senate Office Building (Anthrax)

In mid-October, a letter containing a potent strain of anthrax was opened in the offices used by Senate Majority Leader, Tom Daschle.

- The Hart Building is home to 50 U.S. senators.

- The HVAC system serves the southeast quadrant of the 1-million-sq.-ft. building, including offices on all nine floors.

- The fumigation clean-up process involved using for the first time chlorine dioxide gas solution to remediate Senator Daschle's office and the suite's HVAC system.

Brentwood Post Office (Anthrax)

- Subsequent to the anthrax outbreaks at NBC and the Hart Senate Office Building, it was discovered that the NBC and Daschle letters were sent from the Brentwood Post Office in Trenton, New Jersey.

- Two of the three victims of the anthrax campaign were postal workers employed at the U.S. Post Office in Washington D.C. that sorted mail for the U.S. Congress and handled the letter containing anthrax which was sent to Senator Daschle.

- Studies of the anthrax samples suggested the presence of silica, a recipe involved in U.S. experiments in the 1960s to develop anthrax as a weapon.

Summary of Lessons Learned from past attacks

1. Lessons learned from terrorist attacks are now a matter of national importance, focus, and urgency to ensure our survival.

2. Current building design and construction are inadequate to defend against a planned terrorist attack. The attackers must be intercepted or prevented from infiltrating the interior or the environment.

3. Design planning improvements can be made to minimize damages from terrorist attacks (not including the use of nuclear detonations) by planning the total building environment that leverages security and cost beneficial design improvements.

4. Much can be learned from the last twenty years of terrorist attacks (no more lessons are needed after 9/11).

5. The Murrah Building bombing showed that a truck bomb positioned close to one major building column could create catastrophic building damage.

6. The US embassies bombings in Africa showed that denying entrance to terrorists and maintaining adequate distance could mitigate catastrophic building damage.

7. The 9/11 WTC attack shocked the world forever and raised the bar for security, design improvements and costs.

8. Biological attacks created uncertainty, terror and a need for specialized protection.

It remains to be seen whether building code improvements will be mandated and how terrorist risk will be managed, impacting building design and construction.

Module B: Homeland Security Assessment

Terrorism Design Impact

The premise of terrorism creates tremendous uncertainty for designers regarding the destruction capabilities and safety requirements. This creates several design dilemmas:

- Locality within the community versus proximity to traffic and public access.
- Desirability of workspace versus vulnerability of building environment.
- Degrees of openness of windows and atriums versus structural blast resistance and toughness.
- Designers are faced with architectural criteria that directly contradicts the blast-mitigation objectives.
- Urban settings where the proximity to unregulated traffic brings the terrorist threat to or within the building's perimeter.

Threat/Vulnerability Assessment

All facilities face a certain level of risk associated with various threats. These threats may be the result of natural events, accidents, or terrorism. Regardless of the nature of the threat, facility owners have a responsibility to limit or manage risks from these threats to the maximum extent possible. The federal government has implemented the Interagency Security Committee (ISC) Security Design Criteria. The ISC Security Design Criteria states,

"The application of the Security Design Criteria is based on a project-specific risk assessment that looks at threat, vulnerability, and consequences, three important components of risk ... The building's specific security requirements should be based on a risk assessment—done at the earliest stages of programming ..."

Facility owners, particularly owners of public facilities, should adhere to similar security design criteria as those put forth in the ISC Security Design Criteria. Landlords who desire to lease space to federal government agencies must implement the ISC Security Design Criteria in the design of new facilities and/or the renovation of existing facilities.

In general, the likelihood of terrorist attacks cannot be quantified statistically since terrorism is, by its very nature, random. Therefore, qualitative methodologies must be developed to perform a credible vulnerability assessment through standard risk management techniques.

Threat/Vulnerability Assessment

The first step in a risk management program is a threat assessment. A threat assessment considers the full spectrum of threats (i.e., natural, criminal, terrorist, accidental, etc.) for a given facility/location. The assessment should examine supporting information to evaluate the likelihood of occurrence for each threat. For natural threats, historical data concerning frequency of occurrence for given natural disasters such as tornadoes, hurricanes, floods, fire, or earthquakes can be used to determine the credibility of the given threat. For criminal threats, the crime rates in the surrounding area provide a good indicator of the type of criminal activity that may threaten the facility. In addition, the type of assets and/or activity located in the facility may also increase the target attractiveness in the eyes of the aggressor. The type of assets and/or activity located in the facility will also relate directly to the likelihood of various types of accidents. For example, a facility that utilizes heavy industrial machinery will be at higher risk for serious or life-threatening job related accidents than a typical office building.

For terrorist threats, the attractiveness of the facility as a target is a primary consideration. In addition, the type of terrorist act may vary based on the potential adversary and the method of attack most likely to be successful for a given scenario. For example, a terrorist wishing to strike against the federal government may be more likely to attack a large federal building than to attack a multi-tenant office building containing a large number of commercial tenants and a few government tenants. However, if security at the large federal building makes mounting a successful attack too difficult, the terrorist may be diverted to a nearby facility that may not be as attractive from an occupancy perspective, but has a higher probability of success due to the absence of adequate security. In general, the likelihood of terrorist attacks cannot be quantified statistically since terrorism is, by its very nature, random. Hence, when considering terrorist threats, the concept of developing credible threat packages is important.

Vulnerability Assessment

Once the credible threats are identified, a vulnerability assessment must be performed. The vulnerability assessment considers the potential impact of loss from a successful attack as well as the vulnerability of the facility/location to an attack. Impact of loss is the degree to which the mission of the agency is impaired by a successful attack from the given threat. A key component of the vulnerability assessment is properly defining the ratings for impact of loss and vulnerability. These definitions may vary greatly from facility to facility. For example, the amount of time that mission capability is impaired is an important part of impact of loss. If the facility being assessed is an Air Route Traffic Control Tower, a downtime of a few minutes may be a serious impact of loss, while for a Social Security office a downtime of a few minutes would be minor.

As we recall from Risk Management 101, a risk event is evaluated as follows:

Risk Event = Probability X Impact

The probability of an attack is influenced by the following:

- Attractiveness of a facility as a target
- Level of deterrence and/or defense provided by the existing countermeasures.

Threat probabilities could be defined as:

- *Very high:* This is a high profile, nationally recognized facility that provides a very attractive target and the level of deterrence is inadequate.
- *High:* This is a high profile regional facility or a moderate profile national facility that provides an attractive target and/or the level of deterrence is inadequate.
- *Moderate:* This is a moderate profile facility (not well known outside the local area) that provides a potential target and/or the level of deterrence is marginally adequate.
- *Low:* This is not a high profile facility and provides a possible target and/or the level of deterrence is adequate.

Vulnerability Impact could be defined as:

- *Devastating:* The facility is damaged/contaminated beyond habitable use.
- *Severe:* The facility is partially damaged/contaminated.

- *Noticeable:* The facility is temporarily closed or unable to operate, but can continue without an interruption of more than one day.

- *Minor:* The facility experiences no significant impact on operations and there is no loss of major assets.

The tables below provide an example of a risk matrix that applies the risk management principles outlined above.

Table 1. Matrix identifying levels of risk.

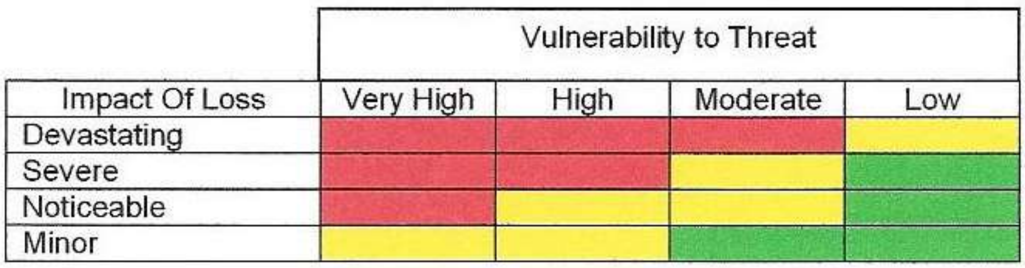
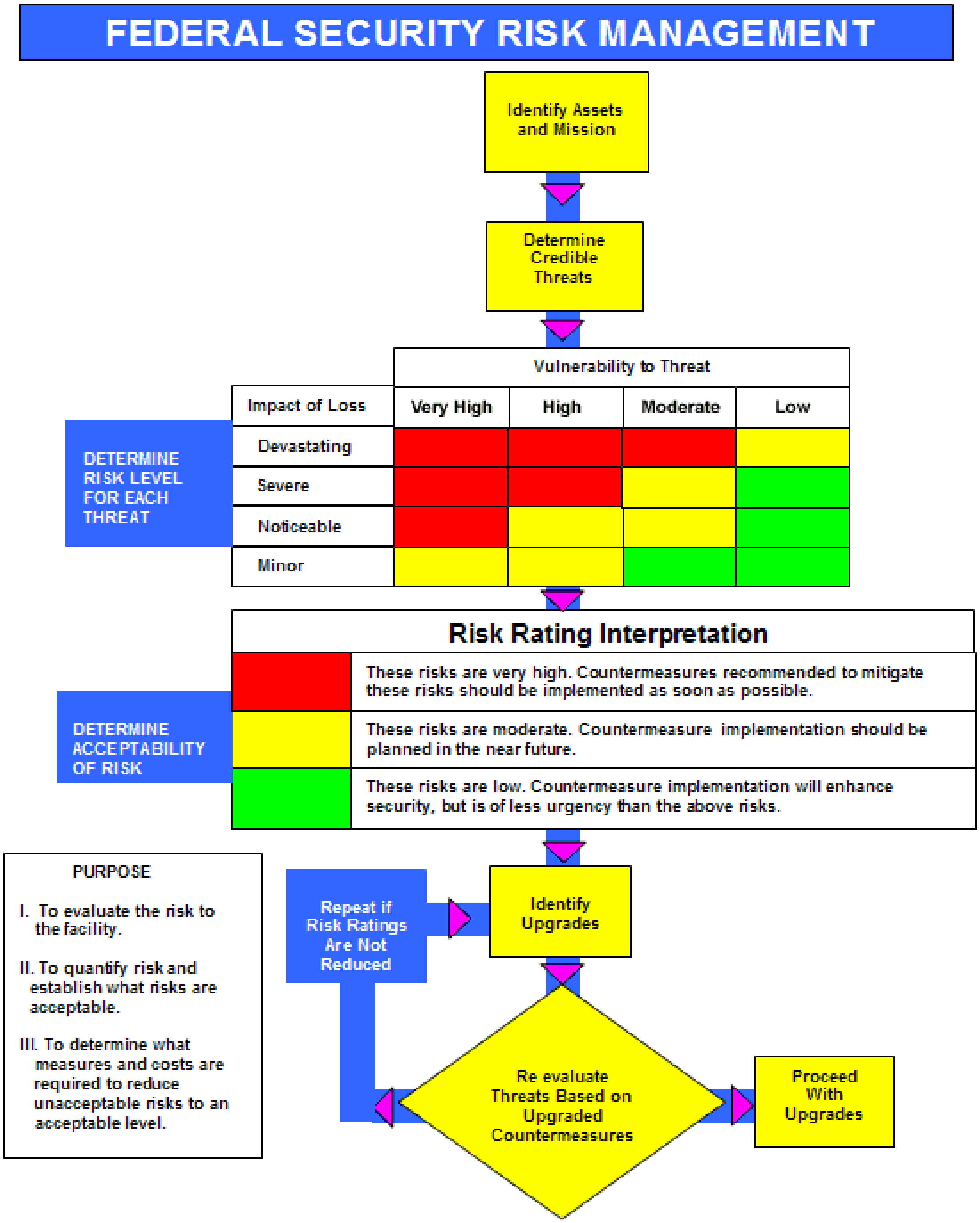


Table 2. Interpretation of the risk ratings

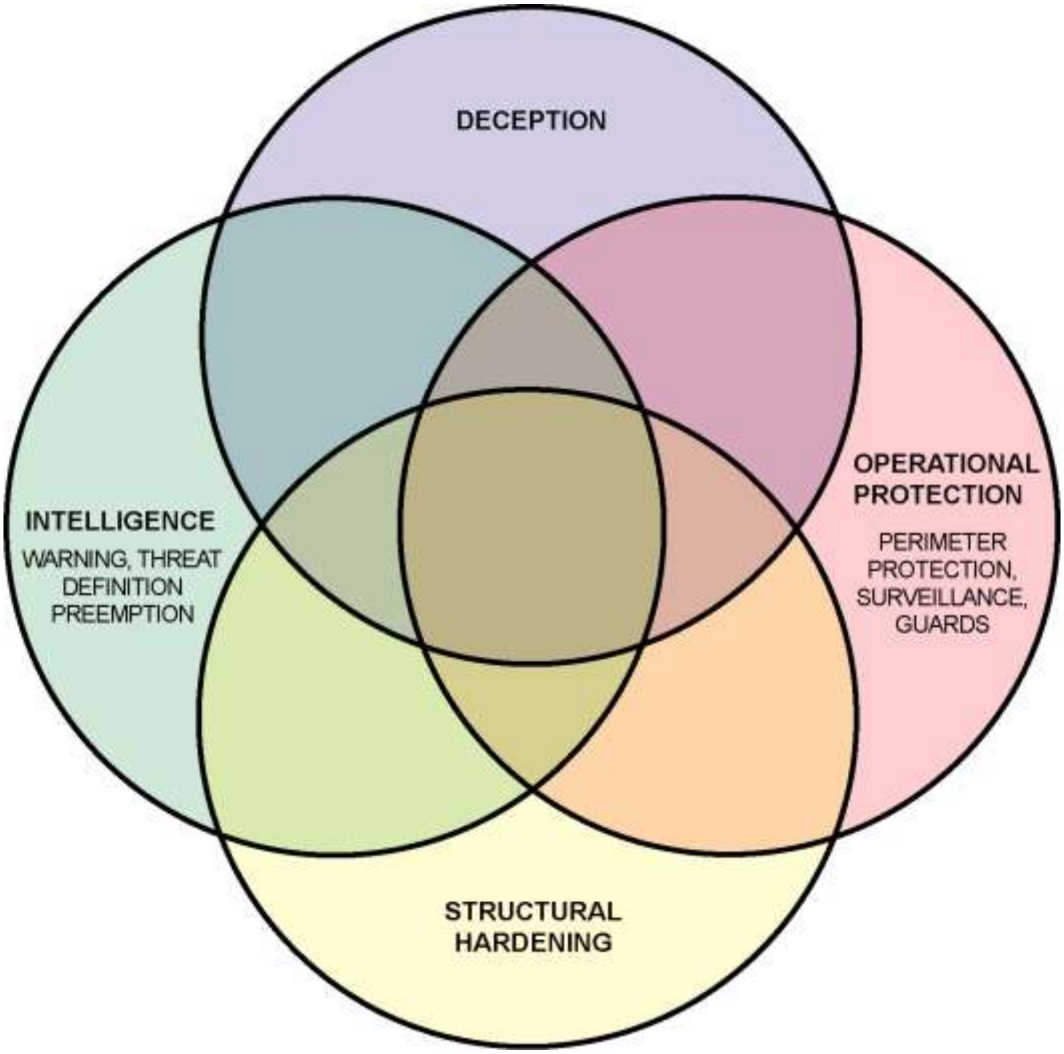
	These risks are high. Countermeasures recommended to mitigate these risks should be implemented as soon as possible.
	These risks are moderate. Countermeasure implementation should be planned in the near future.
	These risks are low. Countermeasure implementation will enhance security, but is of less urgency than the above risks.

The overall threat/vulnerability and risk analysis methodology employed by the federal government is summarized in the flowchart below.



Integrated Security Principles

The overall security of a facility is dependent on the integration of various security principles as indicated below:



1. Ideally, a potential terrorist attack is prevented or pre-empted through intelligence measures.

2. Deception may be used to make the facility appear to be a more protected or a lower-risk facility than it actually is.

3. If an attack does occur, operational protection can be used to provide layers of defense that delay and/or thwart the attack.

4. Structural hardening can be provided to save lives and facilitate evacuation and rescue by preventing building collapse and limiting flying debris.

Priority of Security Goals

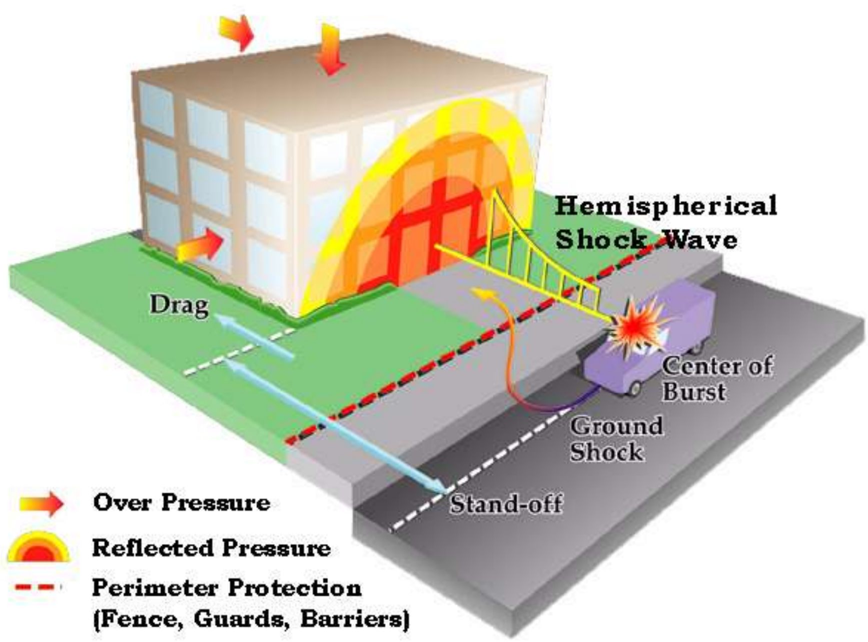
1. Preventing an attack

- Make it more difficult to implement some of the more obvious arrack scenarios.
- Make the target appear to be of low value.

2. Delaying an attack
    - Make it more difficult for the attacker to reach the intended target.
    - Entice the attacker toward non-critical parts of the facility.
3. Mitigating the effects of an attack
    - Provide structural protection to control the extent and consequences of damage.
    - Provide enhanced life-safety systems to save lives.

The Nature of Explosive Attacks

Before we try to solve for some of the risks associated with terrorism, it is important to understand the impact from explosive attacks.



From the standpoint of structural design, the vehicle bomb is the most important consideration. Vehicle bombs are able to deliver a sufficiently large quantity of explosives to cause potentially devastating structural damage. Security design intended to limit or mitigate damage from a vehicle bomb assumes that the bomb is detonated at a so-called critical location (see figure above).

The critical location is a function of the site, the building layout, and the security measures in place. For a vehicle bomb, the critical location is taken to be at the closest point that a vehicle can approach, assuming that all security measures are in place. This may be a parking area directly beneath the occupied building, the loading dock, the curb directly outside the facility, or at a vehicle-access control gate where inspection takes place, depending on the level of protection incorporated into the design.

Another explosive attack threat is the small bomb that is hand delivered. Small weapons can cause the greatest damage when brought into vulnerable, unsecured areas of the building interior, such as the building lobby, mail room, and retail spaces. Recent events around the world make it clear that there is an increased likelihood that bombs will be delivered by persons who are willing to sacrifice their own lives. Hand carried explosives are typically on the order of five to ten pounds of TNT equivalent. However, larger charge weights, in the 50 to 100 pounds TNT equivalent range, can be readily carried in rolling cases. Mail bombs are typically less than ten pounds of TNT equivalent. In general, the largest credible explosive size is a function of the security measures in place. Each line of security may be thought of as a sieve, reducing the size of the weapon that may gain access. Therefore the largest weapons are considered in totally unsecured public space (e.g., in a vehicle on the nearest public street), and the smallest weapons are considered in the most secured areas of the building (e.g., in a briefcase smuggled past the screening station).

Two parameters define the design threat: the weapon size, measured in equivalent pounds of TNT, and the standoff. The standoff is the distance measured from the center of gravity of the charge to the component of interest. The design weapon size is usually selected by the owner in collaboration with security and protective design consultants (i.e., engineers who specialize in the design of structures to mitigate the effects of explosions). Although there are few unclassified sources giving the sizes of weapons that have been used in previous attacks throughout the world, security consultants have valuable information that may be used to evaluate the range of charge weights that might be reasonably considered for the intended occupancy. Security consultants draw upon the experience of other countries such as Great Britain and Israel where terrorist attacks have been more prevalent, as well as data gathered by U.S. sources. To put the weapon size into perspective, it should be noted that thousands of deliberate explosions occur every year within the United States, but the vast majority of them have weapon yields less than five pounds. The number of large-scale vehicle weapon attacks that have used hundreds of pounds of TNT during the past twenty years is by comparison very small. The design vehicle weapon size will usually be much smaller than the largest credible threat. The design weapon size is typically measured in hundreds of pounds rather than thousands of pounds of TNT equivalent. The decision is usually based on a trade-off between the largest credible attack directed against the building and the design constraints of the project. Further, it is common for the design pressures and impulses to be less than the actual peak pressures and impulses acting on the building. This is the approach that the federal government has taken in their design criteria for federally owned domestic office buildings.

There are several reasons for this choice.

1. The likely target is often not the building under design, but a high risk building that is nearby. Historically, more building damage has been due to collateral effects than direct attack.

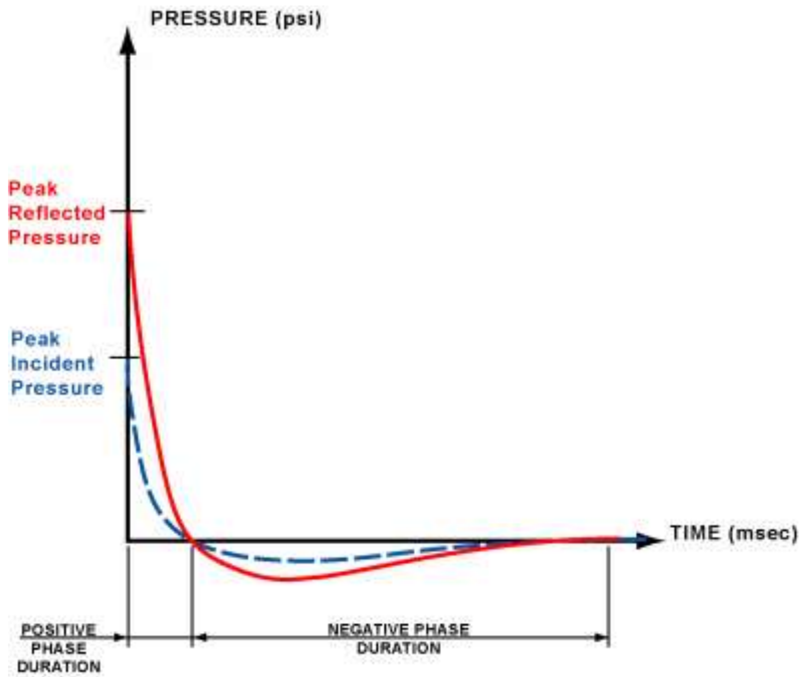
2. It is difficult to quantify the risk of man-made hazards. However, qualitatively it may be stated that the chance of a large-scale terrorist attack occurring is extremely low. A smaller explosive attack is far more likely.

3. Providing a level of protection that is consistent with standards adopted for federal office buildings enhances opportunities for leasing to government agencies in addition to providing a clear statement regarding the building's safety to other potential tenants.

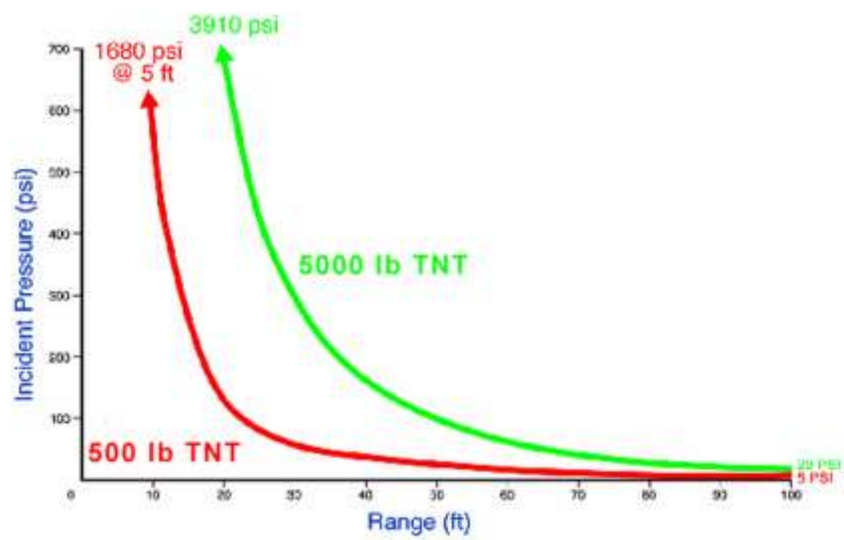
4. The added robustness inherent in designing for a vehicle bomb of moderate size will improve the performance of the building under all explosion scenarios.

Explosive Forces

An explosion is an extremely rapid release of energy in the form of light, heat, sound, and a shock wave. The shock wave consists of highly compressed air that wave-reflects off the ground surface to produce a hemispherical propagation of the wave that travels outward from the source at supersonic velocities. As the shock wave expands, the incident or over-pressures decrease. When it encounters a surface that is in line-of-sight of the explosion, the wave is reflected, resulting in a tremendous amplification of pressure. Unlike acoustical waves, which reflect with an amplification factor of two, shock waves can reflect with an amplification factor of up to thirteen, due to the supersonic velocity of the shock wave at impact. The magnitude of the reflection factor is a function of the proximity of the explosion and the angle of incidence of the shock wave on the surface. The pressures decay rapidly with time (i.e., exponentially), measured typically in thousandths of a second (milliseconds). Diffraction effects, caused by building features such as re-entrant corners and overhangs of the building may act to confine the air blast, prolonging its duration. Late in the explosive event, the shock wave becomes negative, followed by a partial vacuum, which creates suction behind the shock wave (see figure below).



Immediately following the vacuum, air rushes in, creating a powerful wind or drag pressure on all surfaces of the building. This wind picks up and carries flying debris in the vicinity of the detonation. In an external explosion, a portion of the energy is also imparted to the ground, creating a crater and generating a ground shock wave analogous to a high-intensity, short-duration earthquake. The peak pressure is a function of the weapon size or yield, and the cube of the distance (see figure below).



Damages from Explosive Attacks

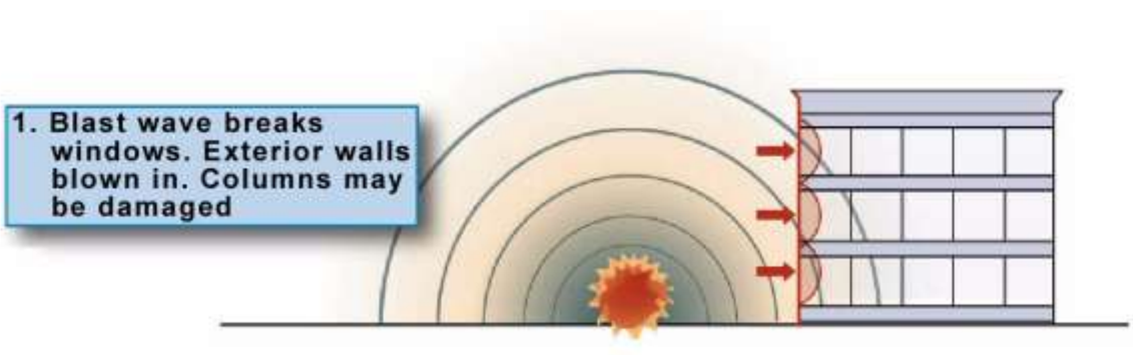
The extent and severity of damage and injuries in an explosive event cannot be predicted with perfect certainty. Past events show that the specifics of the failure sequence for an individual building due to air blast effects and debris impact significantly affect the overall level of damage. For instance, two adjacent columns of a building may be roughly the same distance from the explosion, but only one fails because it is struck by a fragment in a particular way that initiates collapse. The other, by chance, is not struck and remains in place. Similarly, glass failures may occur outside of the predicted areas due to air-blast diffraction effects caused by the arrangement of buildings and their heights in the vicinity of the explosion. The details of the physical setting surrounding a particular occupant may greatly influence the level of injury incurred. The position of the person, seated or standing, facing towards or away from the event as it happens, may result in injuries ranging from minor to severe. Despite these uncertainties, it is possible to calculate the expected extent of damage and injuries to be expected in an explosive event, based on the size of the explosion, distance from the event, and assumptions about the construction of the building. Additionally, there is strong evidence to support a relationship between injury patterns and structural damage patterns.

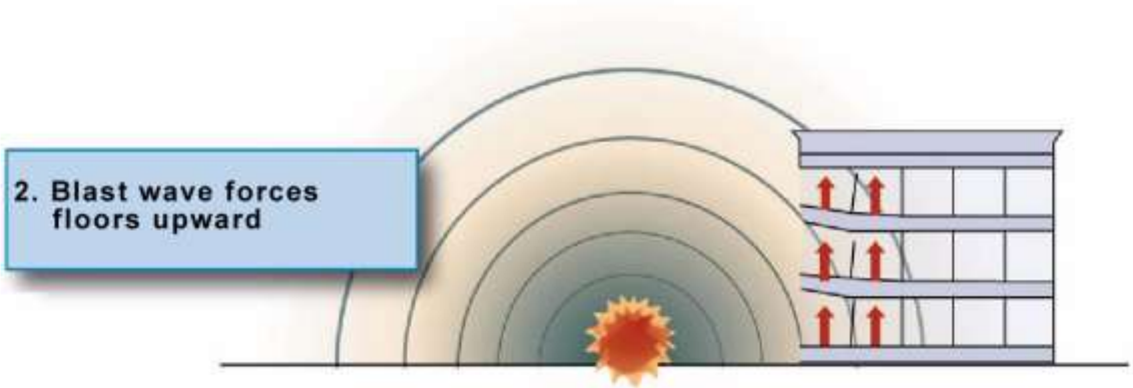
Damage due to the air-blast shock wave may be divided into direct air blast effects and progressive collapse.

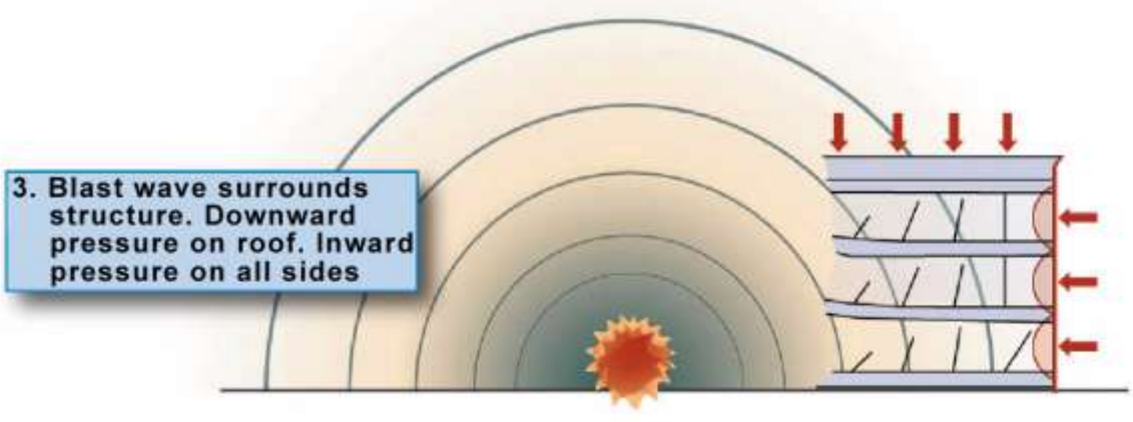
Direct air-blast effects are damage caused by the high-intensity pressures of the air blast close to the explosion. These may induce localized failure of exterior walls, windows, roof systems, floor systems, and columns.

Progressive collapse refers to the spread of an initial local failure from element to element, eventually resulting in a disproportionate extent of collapse relative to the zone of initial damage. Localized damage due to direct air-blast effects may or may not progress, depending on the design and construction of the building. To produce a progressive collapse, the weapon must be in close proximity to a critical load-bearing element. Progressive collapse can propagate vertically upward or downward (e.g., Ronan Point1) from the source of the explosion, and it can propagate laterally from bay to bay as well.

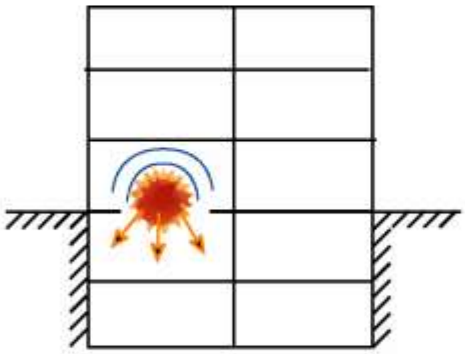
The pressures that an explosion exerts on building surfaces may be several orders of magnitude greater than the loads for which the building is designed. The shock wave also acts in directions that the building may not have been designed for, such as upward pressure on the floor system. In terms of sequence of response, the air blast first impinges the exterior envelope of the building. The pressure wave pushes on the exterior walls and may cause wall failure and window breakage. As the shock wave continues to expand, it enters the structure, pushing both upward on the ceilings and downward on the floors (see figure below).



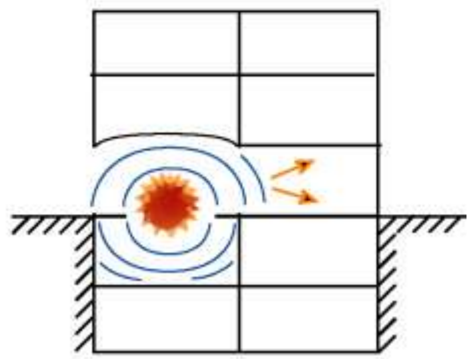




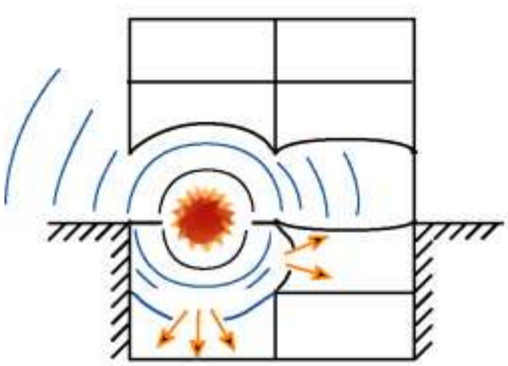
Floor failure is common in large-scale vehicle-delivered explosive attacks, because floor slabs typically have a large surface area for the pressure to act on and a comparably small thickness. Floor failure is particularly common for close-in and internal explosions. The loss of a floor system increases the unbraced height of the supporting columns, which may lead to structural instability. For hand-carried weapons that are brought into the building and placed on the floor away from a primary vertical load-bearing element, the response will be more localized with damage and injuries extending a bay or two in each direction (see figure below).



1. Localized floor breach



2. Ceiling uplift, wall and window failure



3. Air blast venting to exterior, damage and possible failure of floors and walls on levels above and below

Although the weapon is smaller, the air-blast effects are amplified due to multiple reflections from interior surfaces. Typical damage types that may be expected include:

- Localized failure of the floor system immediately below the weapon;
- Damage and possible localized failure for the floor system above the weapon;
- Damage and possible localized failure of nearby concrete and masonry walls;
- Failure of nonstructural elements such as partition walls, false ceilings, ductwork, window treatments; and

- Flying debris generated by furniture, computer equipment, and other contents.

More extensive damage, possibly leading to progressive collapse, may occur if the weapon is strategically placed directly against a primary load-bearing element such as a column. In comparison to other hazards such as earthquake or wind, an explosive attack has several distinguishing features, listed below.

- The intensity of the localized pressures acting on building components can be several orders of magnitude greater than these other hazards. It is not uncommon for the peak pressure on the building from a vehicle weapon parked along the curb to be in excess of 100 psi. Major damage and failure of building components is expected even for relatively small weapons, in close proximity to the building.

- Explosive pressures decay extremely rapidly with distance from the source. Pressures acting on the building, particularly on the side facing the explosion, may vary significantly, causing a wide range of damage types. As a result, air blast tends to cause more localized damage than other hazards that have a more global effect.

- The duration of the event is very short, measured in thousandths of a second, (milliseconds). In terms of timing, the building is engulfed by the shockwave and direct air-blast damage occurs within tens to hundreds of milliseconds from the time of detonation due to the supersonic velocity of the shock wave and the nearly instantaneous response of the structural elements. By comparison, earthquake events last for seconds and wind loads may act on the building for minutes or longer.

Module C: Design Guidelines

This section of the course will provide guidance for limiting or mitigating the effects of terrorist attacks. The design areas addressed include the following:

- Site Location and Layout
- Architectural
- Structural
- Building Envelope
- Mechanical and Electrical Systems
- Chemical, Biological and Radiological Protection

Site Location and Layout Guidance

Because air-blast pressures decrease rapidly with distance, one of the most effective means of protecting assets is to increase the distance between a potential bomb and the assets to be protected. The best way to do this is to provide a continuous line of security along the perimeter of the facility to protect it from unscreened vehicles and to keep all vehicles as far away from critical assets as possible.

Perimeter Line

The perimeter line of protection is the outermost line that can be protected by facility security measures. The perimeter needs to be designed to prevent carriers of large-scale weapons from gaining access to the site. In design, it is assumed that all large-scale explosive weapons (i.e., car bombs or truck bombs) are outside this line of defense. This line is defended by both physical and operational security methods.

It is recommended that the perimeter line be located as far as is practical from the building exterior. Many times, vulnerable buildings are located in urban areas where site conditions are tight. In this case, the options are obviously limited. Often, the perimeter line can be pushed out to the edge of the sidewalk by means of bollards, planters, and other obstacles.

Controlled Access Zones

Access control refers to points of controlled access to the facility through the perimeter line. The controlled access check or inspection points for vehicles require architectural features or barriers to maintain the defensible perimeter. Architects and engineers can accommodate these security functions by providing adequate design for these areas, which makes it difficult for a vehicle to crash onto the site.

Deterrence and delay are major attributes of the perimeter security design that should be consistent with the landscaping objectives, such as emphasizing the open nature characterizing high-population buildings. Since it is impossible to thwart all possible threats, the objective is to make it difficult to successfully execute the easiest attack scenarios such as a car bomb detonated along the curb, or a vehicle jumping the curb and ramming into the building prior to detonation.

If space is available between the perimeter line and the building exterior, much can be done to delay an intruder. Examples include terraced landscaping, fountains, statues, staircases, circular driveways, planters, trees, high-strength cables hidden in bushes and any number of other obstacles that make it difficult to rapidly reach the building. Though individually these features may not be able to stop a vehicle, in combination, they form a daunting obstacle course.

On the sides of the building that are close to the curb, where landscaping solutions are limited, anti-ram barriers capable of stopping a vehicle on impact are recommended for high-risk buildings. Barrier design methods are discussed in more detail below.

The location of access points should be oblique to oncoming streets so that it is difficult for a vehicle to gain enough velocity to break through these access locations. If the site provides straight-on access to the building, some mitigation options include concrete medians in the street to slow vehicles or, for high-risk buildings, use of anti-ram barriers along the curb capable of withstanding the impact of high-velocity vehicles.

Place parking as far as practical from the building. Off-site parking is recommended for high-risk facilities vulnerable to terrorist attack. If on-site surface parking or underground parking is provided, take precautions such as limiting access to these areas only to the building occupants and/or having all vehicles inspected in areas close-in to the building. If an underground area is used for a high-risk building, the garage should be placed adjacent to the building under a plaza area rather than directly underneath the building. To the extent practical, limit the size of vehicle that is able to enter the garage by imposing physical barriers on vehicle height.

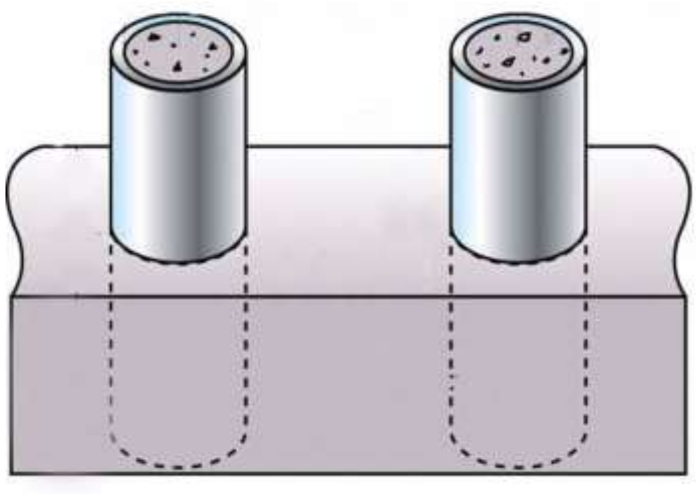
Passive Protective Barriers

Passive barriers are those that are fixed in place and do not allow for vehicle entry. These are to be used away from vehicle access points. The majority of these are constructed in place.

For lower-risk buildings without straight-on vehicular access, it may be appropriate to install surface-mounted systems such as planters, or to use landscaping features to landscaping solution is to install a deep permanent planter around the building with a wall that is as high as a car or truck bumper.

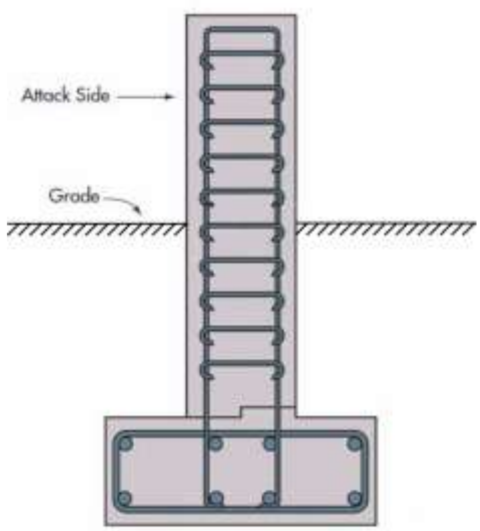
Individual planters mounted on the sidewalk resist impact through inertia and friction between the planter and the pavement. It can be expected that the planter will move as a result of the impact. For a successful design, the maximum displacement of the planter should be less than the setback distance to the building. The structure supporting the weight of the planter must be considered prior to installation. To further reduce displacement, the planter may be placed several inches below the pavement surface. A roughened, grouted interface surface will also improve performance.

The traditional anti-ram solution entails the use of bollards (see figure below).



Bollards are concrete-filled steel pipes that are placed every few feet along the curb of a sidewalk to prevent vehicle intrusion. In order for them to resist the impact of a vehicle, the bollard needs to be fully embedded into a concrete strip foundation that is several feet deep. The height of the bollard above ground should be higher than the bumper of the vehicle. The spacing of the bollards is based on several factors including ADA (American Disabilities Act) requirements, the minimum width of a vehicle, and the number of bollards required to resist the impact. As a rule of thumb, the center-to-center spacing should be between three and five feet to be effective. The height of the bollard is to be at least as high as the bumper of the design threat vehicle, which is taken typically between two and three feet.

An alternative to a bollard is a plinth wall, which is a continuous knee wall constructed of reinforced concrete with a buried foundation (see figure below).



The wall may be fashioned into a bench, a base for a fence, or the wall of a planter. To be effective, the height needs to be at least as high as the vehicle bumper.

For effectiveness, the barriers need to be placed as close to the curb as possible. However, the property line of buildings often does not extend to the curb. Therefore, to place barriers with foundations near the curb, a permit is required by the local authorities, which can be a difficult time-consuming effort to obtain. To avoid this, building owners are often inclined to place bollards along the property line, which significantly reduces the effectiveness of the barrier system.

Active Barrier Systems

At vehicular access points, active or operational anti-ram systems are required. There are off-the-shelf products available that have been rated to resist various levels of car and truck impacts. Solutions include:

- crash beams;
- crash gates;
- surface-mounted plate systems;
- retractable bollards; and
- rotating-wedge systems.

The first three systems listed above generally have lower impact ratings than the last two listed. Check with the manufacturer to ensure that the system has been tested to meet the impact requirements for your project. It is important that the installation of hydraulically operated systems be performed by a qualified contractor to ensure a reliable system that will work properly in all weather conditions.

Summary of Site Location and Layout Design Guidelines:

1. Provide a continuous line of defense around the site as far from the building as practical.

2. Place vehicular access points away from oncoming streets.

3. Limit the number of vehicular entrances through the secured perimeter line.

4. Use a series of landscape features to create an obstacle course between the building and the perimeter. This approach is most effective if used in areas where there is ample setback.

5. Design planter for the design-level impact to displace the planter a distance less than the setback.

6. Use anti-ram barriers along curbs, particularly on sides of the building that have a small setback and in areas where high-velocity impact is possible.

7. Use operable anti-ram barriers at vehicular access points. Select barriers rated to provide the desired level of protection against the design impact.

Architectural Guidance

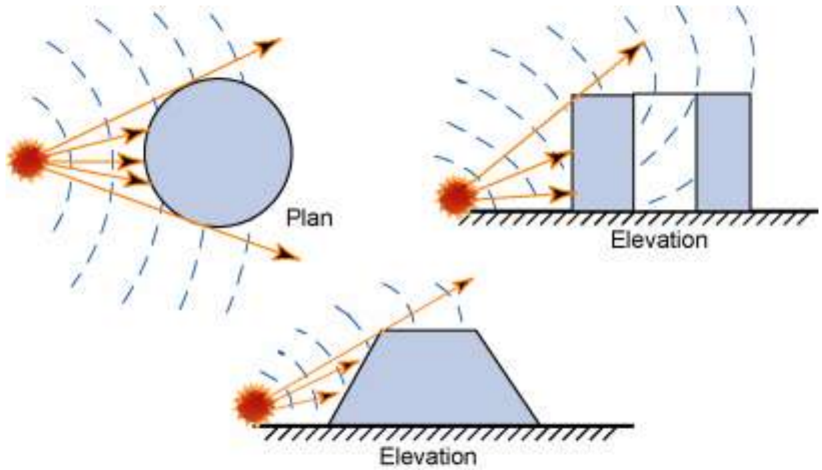
There is much that can be done architecturally to mitigate the effects of a terrorist attack. These design applications are broken down between the building exterior and interior.

Building Exterior

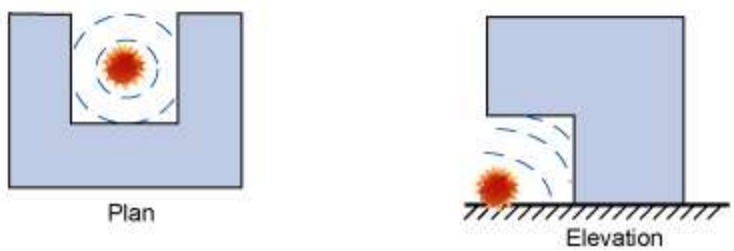
This section discusses the building shape, placement, and exterior ornamentation. At the building exterior, the focus shifts from deterring and delaying the attack to mitigating the effects of an explosion. The exterior envelope of the building is most vulnerable to an exterior explosive threat because it is the part of the building closest to the weapon, and it is typically built using brittle materials. It also is a critical line of defense for protecting the occupants of the building.

The placement of the building on the site can have a major impact on its vulnerability. Ideally, the building is placed as far from the property lines as possible. This applies not only to the sides that are adjacent to streets, but the sides that are adjacent to adjoining properties, since it is not certain who will occupy the neighboring properties during the life of the building. A common, but unfortunate practice is to create a large plaza area in front of the building, but to leave little setback on the sides and rear of the building. Though this practice may increase the monumental character of the building, it also increases the vulnerability of the other three sides.

The shape of the building can have a contributing effect on the overall damage to the structure (see figure below).



SHAPES THAT DISSIPATE AIR BLAST



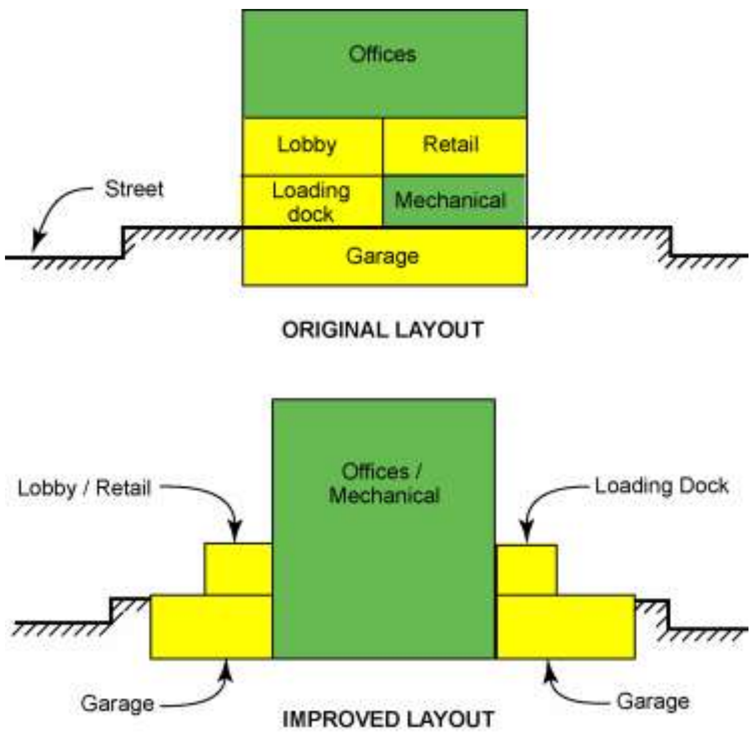
SHAPES THAT ACCENTUATE AIR BLAST

Re-entrant corners and overhangs are likely to trap the shock wave and amplify the effect of the air blast. Note that large or gradual re-entrant corners have less effect than small or sharp re-entrant corners and overhangs. The reflected pressure on the surface of a circular building is less intense than on a flat building. When curved surfaces are used, convex shapes are preferred over concave shapes. Terraces that are treated as roof systems subject to downward loads require careful framing and detailing to limit internal damage to supporting beams. Generally, simple geometries and minimal ornamentation (which may become flying debris during an explosion) are recommended unless advanced structural analysis techniques are used. If ornamentation is used, it is preferable to use lightweight materials such as timber or plastic, which are less likely than brick, stone, or metal to become lethal projectiles in the event of an explosion.

Soil can be highly effective in reducing the impact of a major explosive attack. Bermed walls and buried roof tops have been found to be highly effective for military applications and can be effectively extended to conventional construction. This type of solution can also be effective in improving the energy efficiency of the building. Note that if this approach is taken, no parking can be permitted over the building. Interior courtyards or atriums are other concepts for bringing light and a natural setting to the building without adding vulnerable openings to the exterior.

Building Interior

In terms of functional layout, unsecured areas such as the lobby, loading dock, mail room, garage, and retail areas need to be separated from the secured areas of the building. Ideally, these unsecured areas are placed exterior to the main building or along the edges of the building. For example, a separate lobby pavilion or loading dock area outside of the main footprint of the building (see figure below) provides enhanced protection against damage and potential building collapse in the event of an explosion at these locations.



Similarly, placing parking areas outside the main footprint of the building can be highly effective in reducing the vulnerability to catastrophic collapse. If it is not possible to place vulnerable areas outside the main building footprint, they should be placed along the building exterior, and the building layout should be used to create internal "hard lines" or buffer zones. Secondary stairwells, elevator shafts, corridors, and storage areas should be located between public and secured areas. When determining whether secured and unsecured areas are adjacent to one another, consider the layout on each floor and the relationship between floors. Secured occupied or critical areas should not be placed above or below unsecured areas.

Adequate queuing areas should be provided in front of lobby inspection stations so that visitors are not forced to stand outside during bad weather conditions or in a congested line inside a small lobby while waiting to enter the secured areas. Occupied areas or emergency functions should not be placed immediately adjacent to the lobby, but should be separated by a buffer area such as a storage area or corridor. The interior wall area and exposed structural columns in unsecured lobby areas should be minimized.

Vehicular queuing and inspection stations need to be accounted for in design of the loading docks and vehicle access points. These should be located outside the building along the curb or further away. A parking lane may be used for this purpose.

Emergency functions and elevator shafts are to be placed away from internal parking areas, loading docks and other high-risk areas. In the 1993 World Trade Center bombing incident, elevator shafts became chimneys, transmitting smoke and heat from the explosion in the basement to all levels of the building. This hindered evacuation and resulted in smoke inhalation injuries.

False ceilings, light fixtures, Venetian blinds, ductwork, air conditioners, and other nonstructural components may become flying debris in the event of an explosion. Wherever possible it is recommended that the design be simplified to limit these hazards. Placing heavy equipment such as air conditioners near the floor rather than the ceiling is one idea for limiting this hazard. Using fabric curtains or plastic vertical blinds rather than metal Venetian blinds, and using exposed ductwork as an architectural device are other ideas. Mechanically attaching light fixtures to the slab above as is done in high seismic areas is recommended.

Finally, the placement of furniture can have an effect on injury levels. Desks, conference tables, and other similar furniture should be placed as far from exterior windows facing streets as practical. Desks with computer monitors should be oriented away from the window to prevent injury due to the impact of the monitor.

Summary of Architectural Design Guidelines:

1. Use simple geometries without sharp re-entrant corners.

2. Use lightweight nonstructural elements to reduce flying debris hazards.

3. Place the building on the site as far from the perimeter as practical.

4. Place unsecured areas exterior to the main structure or along the exterior of the building.

5. Separate unsecured and secured areas horizontally and vertically using buffer zones and/or hardening of walls and floors.

6. Provide sufficient queuing areas at lobby and delivery entrances.

7. Limit nonstructural elements such as false ceilings and metal blinds on the interior.

8. Mechanically fasten light fixtures to the floor system above.

9. Place desks and conference tables as far from exterior windows as practical.

10. Orient desks with computer monitors to face away from windows so that the chair back faces the window, not the monitor.

Structural Guidance

Given the evolving nature of the terrorist threat, it is impossible to predict what threats may be of concern during the lifetime of the building; it is therefore prudent to provide protection against progressive collapse initiated by a localized structural failure caused by an undefined threat. Because of the catastrophic consequences of progressive collapse, incorporating these measures into the overall building design should be given the highest priority when considering structural design approaches for mitigating the effects of attacks. Explicit design of secondary structural components to mitigate the direct effects of air-blast enhances life safety by providing protection against localized failure, flying debris, and air blast entering the building. It may also facilitate evacuation and rescue by limiting the overall damage level and improving access by emergency personnel.

Progressive Collapse

ASCE-7 defines three ways to approach the structural design of buildings to mitigate damage due to progressive collapse. Each is described below with an emphasis on how the method is applied in the situation where explosive loads are the initiating cause of collapse.

1. Indirect Method: Consider incorporating general structural integrity measures throughout the process of structural system selection, layout of walls and columns, member proportioning, and detailing of connections to enhance overall structural robustness. In lieu of calculations demonstrating the effects of explosions on buildings, one may use an implicit design approach that incorporates measures to increase the overall robustness of the structure. These measures are discussed in the sub-sections below on structural systems, structural layout, and structural elements. This minimum standard is likely to be the primary method used for design of the type of buildings.

2. Alternate-Load-Path Method: Localize response by designing the structure to carry loads by means of an alternate load path in the event of the loss of a primary load-bearing component. The alternate-load-path method has been selected by agencies including the General Services Administration (GSA) as the preferred approach for preventing progressive collapse. This method provides a formal check of the capability of the structure to resist collapse following the removal of specific elements, such as a building column at the building perimeter. The method does not require characterization of the explosive threat. The structural engineer can usually perform the necessary analyses, with or without guidance from a protective design consultant. However, the analysis is likely to benefit from advice of the protective design consultant regarding element loss scenarios that should be considered in design.

3. Specific Local-Resistance Method: Explicitly design critical vertical load-bearing building components to resist the design-level explosive forces. Explosive loads for a defined threat may be explicitly considered in design by using nonlinear dynamic analysis methods. These are discussed below in the subsection on direct design methods with additional information in the subsection on structural elements. Blast-mitigating structural design or hardening generally focuses on the structural members on the lower floor levels that are closest to defined stationary exterior vehicle weapon threats.

Building Structural Systems

In the selection of the structural system, consider both the direct effects of air-blast and the potential for progressive collapse in the event that a critical structural component fails. The characteristics of air-blast loading have been previously discussed. To resist the direct effects of air-blast, the structural characteristics listed below are desirable.

- Mass. Lightweight construction is unsuitable for providing air-blast resistance. For example, a building with steel deck (without concrete fill) roof construction will have little air-blast resistance.

- Shear Capacity. Primary members and/or their connections should ensure that flexural capacity is achieved prior to shear failure. Avoiding brittle shear failure significantly increases the structure's ability to absorb energy.

- Capacity for Reversing Loads. Primary members and their connections should resist upward pressure. Certain systems such as pre-stressed concrete may have little resistance to upward forces. Seated connection systems for steel and recast concrete may also have little resistance to uplift. The use of headed studs is recommended for affixing concrete fill over steel deck to beams for uplift resistance.

To reduce the risk of progressive collapse in the event of the loss of structural elements, the structural traits listed below should be incorporated.

- Redundancy. The incorporation of redundant load paths in the vertical-load-carrying system helps to ensure that alternate load paths are available in the event of failure of structural elements.

- Ties. An integrated system of ties in perpendicular directions along the principal lines of structural framing can serve to redistribute loads during catastrophic events.

- Ductility. In a catastrophic event, members and their connections may have to maintain their strength while undergoing large deformations.

Historically, the preferred material for explosion-mitigating construction is cast-in-place reinforced concrete. This is the material used for military bunkers, and the military has performed extensive research and testing of its performance. Reinforced concrete has a number of attributes that make it the construction material of choice. It has significant mass, which improves response to explosions, because the mass is often mobilized only after the pressure wave is significantly diminished, reducing deformations. Members can be readily proportioned and reinforced for ductile behavior. The construction is unparalleled in its ability to achieve continuity between the members. Finally, concrete columns are less susceptible to global buckling in the event of the loss of a floor system.

Current testing programs are investigating the effectiveness of various conventional building systems; however, in general the level of protection that may be achieved using these materials is lower than what is achieved using well-designed, cast-in-place, reinforced concrete. The performance of a conventional steel frame with concrete fill over metal deck depends on the connection details. Pre-tensioned or post-tensioned construction provides little capacity for abnormal loading patterns and load reversals. The resistance of load-bearing wall structures varies to a great extent.

Structural Layout

To enhance the overall robustness of the structure, the measures listed below are recommended.

- In frame structures, column spacing should be limited. Large column spacing decreases likelihood that the structure will be able to redistribute load in event of column failure.

- The exterior bay is the most vulnerable to damage, particularly for buildings that are close to public streets. It is also less capable of redistributing loads in the event of member loss, since two-way load distribution is not possible. It is desirable to have a shallow bay adjacent to the building exterior to limit the extent of damage.

- Use of transfer girders is strongly discouraged. Loss of a transfer girder or one of its supports can destabilize a significant area of the building. Transfer girders are often found at the building exterior to accommodate loading docks or generous entries, increasing their vulnerability to air-blast effects. It is highly desirable to add redundant transfer systems where transfer girders are required.

- In bearing-wall systems that rely primarily on interior cross-walls, interior longitudinal walls should be periodically spaced to enhance stability and to control the lateral progression of damage.

- In bearing-wall systems that rely on exterior walls, perpendicular walls or substantial pilasters should be provided at a regular spacing to control the mount of wall that is likely to be affected.

Exterior Frame

Because columns do not have much surface area, air-blast loads on columns tend to be mitigated by "clear-time effects". This refers to the pressure wave washing around these slender tall members, and consequently the entire duration of the pressure wave does not act upon them. On the other hand, the critical threat is directly across from them, so they are loaded with the peak reflected pressure, which is typically several times larger than the incident or overpressure wave that is propagating through the air.

For columns subjected to a vehicle weapon threat on an adjacent street, buckling and shear are the primary effects to be considered in analysis. If a very large weapon is detonated close to a column, shattering of the concrete due to multiple tensile reflections within the concrete section can destroy its integrity.

Buckling is a concern if lateral support is lost due to the failure of a supporting floor system. This is particularly important for buildings that are close to public streets. In this case, exterior columns should be capable of spanning two or more stories without buckling. Slender steel columns are at substantially greater risk than are concrete columns.

Confinement of concrete using columns with closely spaced closed ties or spiral reinforcing will improve shear capacity, improve the performance of lap splices in the event of loss of concrete cover, and greatly enhance column ductility. The potential benefit from providing closely spaced closed ties in exterior concrete columns is very high relative to the cost of the added reinforcement.
For steel columns, splices should be placed as far above grade level as practical. It is recommended that splices at exterior columns that are not

specifically designed to resist air-blast loads employ complete-penetration welded flanges. Welding details, materials, and procedures should be selected to ensure toughness.

For a package weapon, column breach is a major consideration. Some suggestions for mitigating this concern are listed below.

- Do not use exposed columns that are fully or partially accessible from the building exterior. Arcade columns should be avoided.

- Use an architectural covering that is at least six inches from the structural member. This will make it considerably more difficult to place a weapon directly against the structure. Because explosive pressures decay so rapidly, every inch of distance will help to protect the column.

Load- bearing reinforced concrete wall construction can provide a considerable level of protection if adequate reinforcement is provided to achieve ductile behavior. This may be an appropriate solution for the parts of the building that are closest to the secured perimeter line (within twenty feet). Masonry is a much more brittle material that is capable of generating highly hazardous flying debris in the event of an explosion. Its use is generally discouraged for new construction.

Spandrel beams of limited depth generally do well when subjected to air blast. In general, edge beams are very strongly encouraged at the perimeter of concrete slab construction to afford frame action for redistribution of vertical loads and to enhance the shear connection of floors to columns.

Roof Systems

The primary loading on the roof is the downward air-blast pressure. The exterior bay roof system on the side(s) facing an exterior threat is the most critical. The air-blast pressure on the interior bays is less intense, so the roof there may require less hardening. Secondary loads include upward pressure due to the air blast penetrating through openings and upward suction during the negative loading phase. The upward pressure may have an increased duration due to multiple reflections of the internal air-blast wave. It is conservative to consider the downward and upward loads separately.

The preferred system is cast-in-place reinforced concrete with beams in two directions. If this system is used, beams should have continuous top and bottom reinforcement with tension lap splices. Stirrups to develop the bending capacity of the beams closely spaced along the entire span are recommended.
Somewhat lower levels of protection are afforded by conventional steel beam construction with a steel deck and concrete fill slab. The performance of this system can be enhanced by use of normal-weight concrete fill instead of lightweight fill, increasing the gauge of welded wire fabric reinforcement, and making the connection between the slab and beams with shear connector studs. Since it is anticipated that the slab capacity will exceed that of the supporting beams, beam end connections should be capable of developing the ultimate flexural capacity of the beams to avoid brittle failure. Beam-to-column connections should be capable of resisting upward as well as downward forces.

Pre-cast and pre-/post-tensioned systems are generally considered less desirable, unless members and connections are capable of resisting upward forces generated by rebound from the direct pressure and/or the suction from the negative pressure phase of the air blast.

Concrete flat slab/plate systems are also less desirable because of the potential of shear failure at the columns. When flat slab/plate systems are used, they should include features to enhance their punching shear resistance. Continuous bottom reinforcement should be provided through columns in two directions to retain the slab in the event that punching shear failure occurs. Edge beams should be provided at the building exterior.

Lightweight systems, such as un-topped steel deck or wood frame construction, are considered to afford minimal resistance to air-blast. These systems are prone to failure due to their low capacity for downward and uplift pressures.

Floor Systems

The floor system design should consider three possible scenarios: air-blast loading, redistributing load in the event of loss of a column or wall support below, and the ability to arrest debris falling from the floor or roof above.

For structures in which the interior is secured against bombs of moderate size by package inspection, the primary concern is the exterior bay framing. For buildings that are separated from a public street only by a sidewalk, the uplift pressures from a vehicle weapon may be significant enough to cause possible failure of the exterior bay floors for several levels above ground. Special concern exists in the case of vertical irregularities in the architectural system, either where the exterior wall is set back from the floor above or where the structure steps back to form terraces. The recommendations of Section 6.3.5.2 for roof systems apply to these areas.

Structural hardening of floor systems above unsecured areas of the building such as lobbies, loading docks, garages, mailrooms, and retail spaces should be considered. In general, critical or heavily occupied areas should not be placed underneath unsecured areas, since it is virtually impossible to prevent against localized breach in conventional construction for package weapons placed on the floor.

Pre-cast panels are problematic because of their tendency to fail at the connections. Pre-/post-tensioned systems tend to fail in a brittle manner if stressed much beyond their elastic limit. These systems are also not able to accept upward loads without additional reinforcement. If pre-/post-tensioned systems are used, continuous mild steel needs to be added to the top and the bottom faces to provide the ductility needed to resist explosion loads.

Flat slab/plate systems are also less desirable because of limited two way action and the potential for shear failure at the columns. When flat slab/plate systems are employed, they should include features to enhance their punching shear resistance, and continuous bottom reinforcement should be provided across columns to resist progressive collapse. Edge beams should be provided at the building exterior.

Interior Columns

Interior columns in unsecured areas are subject to many of the same issues as exterior columns. If possible, columns should not be accessible within these areas. If they are accessible, then obscure their location or impose a standoff to the structural component through the use of cladding. Methods of hardening columns include using closely spaced ties, spiral reinforcement, and architectural covering at least six inches from the structural elements.

Composite steel and concrete sections or steel plating of concrete columns can provide higher levels of protection. Columns in unsecured areas should be designed to span two or three stories without buckling in the event that the floor below and possibly above the detonation area have failed, as previously discussed.

Interior Walls

Interior walls surrounding unsecured spaces are designed to contain the explosive effects within the unsecured areas. Ideally, unsecured areas are located adjacent to the building exterior so that the explosive pressure may be vented outward as well.

Fully grouted CMU (concrete masonry unit) block walls that are well reinforced vertically and horizontally and adequately supported laterally are a common solution. Anchorage at the top and bottom of walls should be capable of developing the full flexural capacity of the wall. Lateral support at the top of the walls may be achieved using steel angles anchored into the floor system above. Care should be taken to terminate bars at the top of the wall with hooks or heads and to ensure that the upper course of block is filled solid with grout. The base of the wall may be anchored by reinforcing bar dowels.

Interior walls can also be effective in resisting progressive collapse if they are designed properly with sufficient load-bearing capacity and are tied into the floor systems below and above. This design for hardened interior wall construction is also recommended for primary egress routes to protect against explosions, fire, and other hazards trapping occupants.

Summary of Structural Design Guidelines:

1. Incorporate measures to prevent progressive collapse.

2. Design floor systems for uplift in unsecured areas and in the exterior bays that may pose a hazard to occupants.

3. Limit column spacing.

4. Avoid transfer girders.

5. Use two-way floor and roof systems.

6. Use fully grouted, heavily reinforced CMU block walls that are properly anchored in order to separate unsecured areas from critical functions and occupied secured areas.

7. Use dynamic nonlinear analysis methods for design of critical structural components.

Building Envelope Guidance

Building Envelope components such as exterior wall/cladding and window systems and other openings are discussed in this section.

Exterior Wall/Cladding

The exterior walls provide the first line of defense against the intrusion of the air-blast pressure and hazardous debris into the building. They are subject to direct reflected pressures from an explosive threat located directly across from the wall along the secured perimeter line. If the building is more than four stories high, it may be advantageous to consider the reduction in pressure with height due to the increased distance and angle of incidence. The objective of design at a minimum is to ensure that these members fail in a ductile mode such as flexure rather than a brittle mode such as shear. The walls also need to be able to resist the loads transmitted by the windows and doors. It is not uncommon, for instance, for bullet-resistant windows to have a higher ultimate capacity than the walls to which they are attached. Beyond ensuring a ductile failure mode, the exterior wall may be designed to resist the actual or reduced pressure levels of the defined threat. Note that special reinforcing and anchors should be provided around blast-resistant window and door frames.

Poured-in-place, reinforced concrete will provide the highest level of protection, but solutions like pre-cast concrete, CMU block, and metal stud systems may also be used to achieve lower levels of protection.

For pre-cast panels, consider a minimum thickness of five inches exclusive of reveals, with two-way, closely spaced reinforcing bars to increase ductility and reduce the chance of flying concrete fragments. The objective is to reduce the loads transmitted into the connections, which need to be designed to resist the ultimate flexural resistance of the panels. Also, connections into the structure should provide as straight a line of load transmittal as practical.

For CMU block walls, use eight-inch block walls, fully grouted with vertically centered heavy reinforcing bars and horizontal reinforcement placed at each layer. Connections into the structure should be designed to resist the ultimate lateral capacity of the wall. For infill walls, avoid transferring loads into the columns if they are primary load-carrying elements. The connection details may be very difficult to construct. It will be difficult to have all the blocks fit over the bars near the top, and it will be difficult to provide the required lateral restraint at the top connection. A preferred system is to have a continuous exterior CMU wall that laterally bears against the floor system. For increased protection, consider using 12-inch blocks with two layers of vertical reinforcement.

For metal stud systems, use metal studs back-to-back and mechanically attached, to minimize lateral torsional effects. To catch exterior cladding fragments, attach a wire mesh or steel sheet to the exterior side of the metal stud system. The supports of the wall should be designed to resist the ultimate lateral out-of-plane bending capacity load of the system.

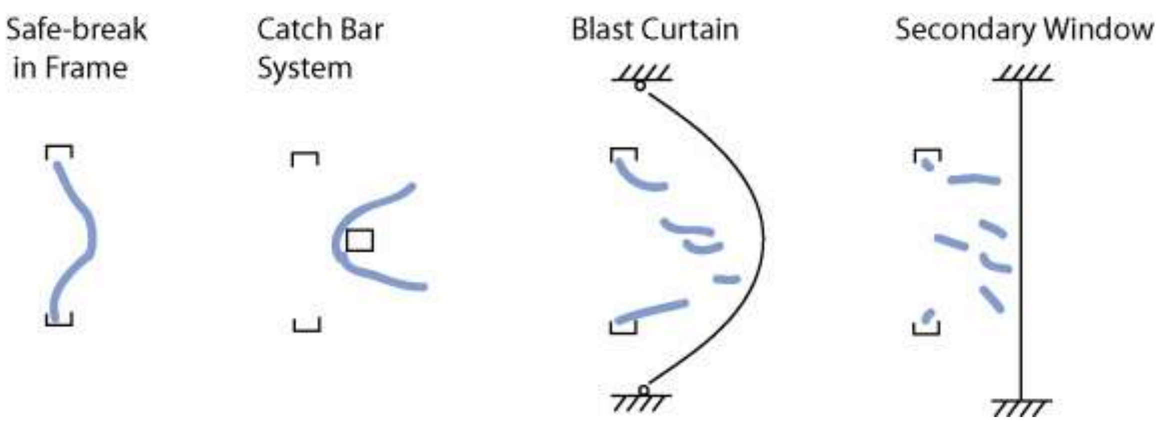
Brick veneers and other nonstructural elements attached to the building exterior are to be avoided or have strengthened connections to limit flying debris and to improve emergency egress by ensuring that exits remain passable.

Windows

Windows, once the sole responsibility of the architect, become a structural issue when explosive effects are taken into consideration. In designing windows to mitigate the effects of explosions they should first be designed to resist conventional loads and then be checked for explosive load effects and balanced design. Balanced or capacity design philosophy means that the glass is designed to be no stronger than the weakest part of the overall window system, failing at pressure levels that do not exceed those of the frame, anchorage, and supporting wall system. If the glass is stronger than the supporting members, then the window is likely to fail with the whole panel entering into the building as a single unit, possibly with the frame, anchorage, and the wall attached. This failure mode is considered more hazardous than if the glass fragments enter the building, provided that the fragments are designed to minimize injuries. By using a damage-limiting approach, the damage sequence and extent of damage can be controlled.

Windows are typically the most vulnerable portion of any building. Though it may be impractical to design all the windows to resist a large-scale explosive attack, it is desirable to limit the amount of hazardous glass breakage to reduce the injuries. Typical annealed glass windows break at low pressure and impulse levels and the shards created by broken windows are responsible for many of the injuries incurred during a large-scale explosive attack.

Designing windows to provide protection against the effects of explosions can be effective in reducing the glass laceration injuries in areas that are not directly across from the weapon. For a large-scale vehicle weapon, this pressure range is expected on the sides of surrounding buildings not facing the explosion or for smaller explosions in which pressures drop more rapidly with distance. Generally, it is not known on which side of the building the attack will occur, so all sides need to be protected. Window protection should be evaluated on a case-by-case basis by a qualified protective design consultant to develop a solution that meets established objectives. Several recommended solutions for the design of the window systems to reduce injuries to building occupants are provided in figure below.



Several approaches can be taken to limit glass laceration injuries. One way is to reduce the number and size of windows. If blast-resistant walls are used, then fewer and/or smaller windows will allow less air blast to enter the building, thus reducing the interior damage and injuries. Specific examples of how to incorporate these ideas into the design of a new building include:

1. Limiting the number of windows on the lower floors where the pressures would be higher during an external explosion;

2. Using an internal atrium design with windows facing inward, not outward;

3. Using clerestory windows, which are close to the ceiling, above the heads of the occupants; and

4. Angling the windows away from the curb to reduce the pressure levels.

Glass curtain-wall, butt glazed, and Pilkington type systems have been found to perform surprisingly well in recent explosive tests with low explosive loads. In particular, glass curtain wall systems have been shown to accept larger deformations without the glass breaking hazardously, compared to rigidly supported punched window systems. Some design modifications to the connections, details, and member sizes may be required to optimize the performance.

Glass

Glass is often the weakest part of a building, breaking at low pressures compared to other components such as the floors, walls, or columns. Past incidents have shown that glass breakage and associated injuries may extend many thousands of feet in large external explosions. High-velocity glass fragments have been shown to be a major contributor to injuries in such incidents. For incidents within downtown city areas, falling glass poses a major hazard to passersby and prolongs post-incident rescue and clean-up efforts by leaving tons of glass debris on the street. At this time, the issue of exterior debris is largely ignored by existing criteria.

As part of the damage-limiting approach, glass failure is not quantified in terms of whether breakage occurs or not, but rather by the hazard it causes to the occupants. Two failure modes that reduce the hazard posed by window glass are glass that breaks but is retained by the frame and glass fragments exit the frame and fall within three to ten feet of the window.

The preferred solution for new construction is to use laminated annealed (i.e., float) glass with structural sealant around the inside perimeter. For insulated units, only the inner pane needs to be laminated. The lamination holds the shards of glass together in explosive events, reducing its ability to cause laceration injuries. The structural sealant helps to hold the pane in the frame for higher loads. Annealed glass is used because it has a breaking strength that is about one-half that of heat-strengthened glass and about one-fourth as strong as tempered glass. Using annealed glass becomes particularly important for buildings with lightweight exterior walls using for instance, metal studs, dry wall, and brick facade. Use the thinnest overall glass thickness that is acceptable based on conventional load requirements. Also, it is important to use an interlayer thickness that is 60 mil thick rather than 30 mil thick, as is used in conventional applications. This layup has been shown to perform well in low-pressure regions (i.e., under about 5 psi). If a 60 mil polyvinyl butaryl (PVB) layer is used, the tension membrane forces into the framing members need to be considered in design.

To make sure that the components supporting the glass are stronger than the glass itself, specify a window breakage strength that is high compared to what is used in conventional design. The breakage strength in window design may be specified as a function of the number of windows expected to break at that load. For instance, in conventional design, it is typical to use a breakage pressure corresponding to eight breaks out of 1000. When a lot of glass breakage is expected, such as for an explosive incident, use a pressure corresponding to 750 breaks out of 1000 to increase confidence that the frame does not fail, too. Glass breakage strength values may be obtained from window manufacturers.

Window Mullions

The frame members connecting adjoining windows are referred to as mullions. These members may be designed in two ways. Using a static approach, the breaking strength of the window glass is applied to the mullion; alternatively, a dynamic load can be applied using the peak pressure and impulse values. The static approach may lead to a design that is not practical, because the mullion can become very deep and heavy, driving up the weight and cost of the window system. It may also not be consistent with the overall architectural objectives for the project. As with frames, it is good engineering practice to limit the number of interlocking parts used for the mullion.

Window Frames

Window frames need to retain the glass so that the entire pane does not become a single large unit of flying debris. It also needs to be designed to resist the breaking stress of the window glass.

To retain the glass in the frame, a minimum of a 1/4-inch bead of structural sealant (e.g., silicone) should be used around the inner perimeter of the window. The allowable tensile strength should be at least 20 psi. Also, the window bite

(i.e., the depth of window captured by the frame) needs to be at least 1/2 inch. The structural sealant recommendations should be determined on a case-by-case basis. In some applications, the structural sealant may govern the overall design of the window system.
Frame and anchorage design is performed by applying the breaking strength of the window to the frame and the fasteners. In most conventionally designed buildings, the frames will be aluminum. In some applications, steel frames are used. Also, in lobby areas where large panes of glass are used, a larger bite with more structural sealant may be needed.

Inoperable windows are generally recommended for air-blast mitigating designs. However, some operable window designs are conceptually viable. For instance, designs in which the window rotates about a horizontal hinge at the head or sill and opens in the outward direction may perform adequately. In these designs, the window will slam shut in an explosion event. If this type of design is used, the governing design parameter may be the capacity of the hinges and/or hardware.

Window Supporting Walls

The supporting wall response should be checked using approaches similar to those for frames and mullions. It does not make sense, and is potentially highly hazardous, to have a wall system that is weaker than windows. Remember that the maximum strength of any wall system needs to be at least equal to the window strength. If the walls are unable to accept the loads transmitted by the mullions, the mullions may need to be anchored into the structural slabs or spandrel beams. Anchoring into columns is generally discouraged, because it increases the tributary area of lateral load that is transferred into the columns and may cause instability.

The balanced-design approach is particularly challenging in the design of ballistic-resistant and forced-entry-resistant windows, which consist of one or more inches of glass and polycarbonate. These windows can easily become stronger than the supporting wall. In these cases, the windows may need to be designed for the design threat air-blast pressure levels under the implicit assumption that balanced-design conditions will not be met for larger loads.

Summary of Building Envelope Design Guidelines:

1. Use the thinnest panel thickness that is acceptable for conventional loads.

2. Design cladding supports and the supporting structure to resist the ultimate lateral resistance of the panel.

3. Design cladding connections to have as direct a load transmission path into the main structure as practical. A good transmission path minimizes shear and torsional response.

4. Avoid framing cladding into columns and other primary vertical load-carrying members. Instead frame into floor diaphragms.

5. Use the thinnest glass section that acceptable for conventional loads.

6. Design window systems so that the frame anchorage and the supporting wall are capable of resisting the breaking pressure of the window glass.
7. Use laminated annealed glass (for insulated panels, only the interior pane needs to be laminated).

8. Design window frames with a minimum of a ½-inch bite.

9. Use a minimum of a ¼-inch silicone sealant around the inside glass perimeter, with a minimum tensile strength of 2- psi.

Mechanical and Electrical System Guidance

The key concepts for providing secure and effective mechanical and electrical systems in buildings is the same as for the other building systems: separation, hardening, and redundancy. Keeping critical mechanical and electrical functions as far from high-threat areas as possible (e.g., lobbies, loading docks, mail rooms, garages, and retail spaces) increases their ability to survive an event. Separation is perhaps the most cost-effective option. Additionally, physical hardening or protection of these systems (including the conduits, pipes, and ducts associated with life-safety systems) provides increased likelihood that they will be able to survive the direct effects of the event if they are close enough to be affected. Finally, by providing redundant emergency systems that are adequately separated, there is a greater likelihood that emergency systems will remain operational post-event to assist rescuers in the evacuation of the building.

Architecturally, enhancements to mechanical and electrical systems will require additional space to accommodate additional equipment. Fortunately, there are many incremental improvements that can be made that require only a small change to the design. Additional space can be provided for future enhancements as funds or the risk justify implementation.

Structurally, the walls and floor systems adjacent to the areas where critical equipment is located need to be protected by means of hardening. Other areas where hardening is recommended include primary egress routes, feeders for emergency power distribution, sprinkler systems mains and risers, fire alarm system trunk wiring, and ducts used for smoke-control systems.

From an operational security standpoint, it is important to restrict and control access to air-intake louvers, mechanical and electrical rooms, telecommunications spaces and rooftops by means of such measures as visitor screening, limited elevator stops, closed-circuit television (CCTV), detection, and card access-control systems.

Specific recommendations are given below for emergency egress routes, the emergency power system, fuel storage, transformers, ventilation systems, the fire control center, emergency elevators, the smoke and fire detection and alarm system, the sprinkler/standpipe system, smoke control system, and the communication system.

Emergency Egress Routes

To facilitate evacuation, consider these measures.

- Provide positive pressurization of stairwells and vestibules.
- Provide battery packs for lighting fixtures and exit signs.
- Harden walls using reinforced CMU block properly anchored at supports.
- Use non-slip phosphorescent treads.
- Do not cluster egress routes in single shaft. Separate them as far as possible.
- Use double doors for mass evacuation.
- Do not use glass along primary egress routes or stairwells.

Emergency Power System

An emergency generator provides an alternate source of power should utility power become unavailable to critical life-safety systems such as alarm systems, egress lighting fixtures, exit signs, emergency communications systems, smoke-control equipment, and fire pumps.

Emergency generators typically require large louvers to allow for ventilation of the generator while running. Care should be taken to locate the generator so that these louvers are not vulnerable to attack. A remote radiator system could be used to reduce the louver size.

Redundant emergency generator systems remotely located from each other enable the supply of emergency power from either of two locations. Consider locating emergency power-distribution feeders in hardened enclosures, or encased in concrete, and configured in redundant routing paths to enhance reliability. Emergency distribution panels and automatic transfer switches should be located in rooms separate from the normal power system (hardened rooms, where possible).

Emergency lighting fixtures and exit signs along the egress path could be provided with integral battery packs, which locates the power source directly at the load, to provide lighting instantly in the event of a utility power outage.

Fuel storage

A non-explosive fuel source, such as diesel fuel, is acceptable for standby use for emergency generators and diesel fire pumps. Fuel tanks should be located away from building access points, in fire-rated, hardened enclosures. Fuel piping within the building should be located in hardened enclosures, and redundant piping systems could be provided to enhance the reliability of the fuel distribution system. Fuel filling stations should be located away from public access points and monitored by the CCTV system.

Transformers

Main power transformer(s) should be located interior to the building if possible, away from locations accessible to the public. For larger buildings, multiple transformers, located remotely from each other, could enhance reliability should one transformer be damaged by an explosion.

Ventilation Systems

Air-intake locations should be located as high up in the building as is practical to limit access to the general public. Systems that serve public access areas such as mail receiving rooms, loading docks, lobbies, freight elevators/lobbies should be isolated and provided with dedicated air handling systems capable of 100 percent exhaust mode. Tie air intake locations and fan rooms into the security surveillance and alarm system.

Building HVAC systems are typically controlled by a building automation system, which allows for quick response to shut down or selectively control air conditioning systems. This system is coordinated with the smoke-control and fire-alarm systems.

Fire Control Center

A Fire Control Center should be provided to monitor alarms and life-safety components, operate smoke-control systems, communicate with occupants, and control the fire-fighting/evacuation process. Consider providing redundant Fire Control Centers remotely located from each other to allow system operation and control from alternate locations. The Fire Control Center should be located near the point of firefighter access to the building. If the control center is adjacent to lobby, separate it from the lobby using a corridor or other buffer area. Provide hardened construction for the Fire Control Center.

Emergency Elevators

Elevators are not used as a means of egress from a building in the event of a life-safety emergency event, as conventional elevators are not suitably protected from the penetration of smoke into the elevator shaft. An unwitting passenger could be endangered if an elevator door opens onto a smoke filled lobby. Firefighters may elect to manually use an elevator for firefighting or rescue operation.

A dedicated elevator, within its own hardened, smoke-proof enclosure, could enhance the firefighting and rescue operation after a blast/fire event. The dedicated elevator should be supplied from the emergency generator, fed by conduit/wire that is protected in hardened enclosures. This shaft/lobby assembly should be sealed and positively pressurized to prevent the penetration of smoke into the protected area.

Smoke and Fire Detection and Alarm System

A combination of early-warning smoke detectors, sprinkler-flow switches, manual pull stations, and audible and visual alarms provide quick response and notification of an event. The activation of any device will automatically start the sequence of operation of smoke control, egress, and communication systems to allow occupants to quickly go to a safe area. System designs should include redundancy such as looped infrastructure wiring and distributed intelligence such that the severing of the loop will not disable the system.

Install a fire-alarm system consisting of distributed intelligent fire alarm panels connected in a peer-to-peer network, such that each panel can function independently and process alarms and initiate sequences within its respective zone.

Sprinkler/Standpipe System

Sprinklers will automatically suppress fire in the area upon sensing heat. Sprinkler activation will activate the fire alarm system. Standpipes have water available locally in large quantities for use by professional fire fighters. Multiple sprinkler and standpipe risers limit the possibility of an event severing all water supply available to fight a fire.

Redundant water services would increase the reliability of the source for sprinkler protection and fire suppression. Appropriate valving should be provided where services are combined. Redundant fire pumps could be provided in remote locations. These pumps could rely on different sources, for example one electric pump supplied from the utility and/or emergency generator and a second diesel fuel source fire pump. Diverse and separate routing of standpipe and sprinkler risers within hardened areas will enhance the system’s reliability (i.e., reinforced masonry walls at stair shafts containing standpipes).

Smoke-Control Systems

Appropriate smoke-control systems maintain smoke-free paths of egress for building occupants through a series of fans, ductwork, and fire-smoke dampers. Stair pressurization systems maintain a clear path of egress for occupants to safe areas or to evacuate the building. Smoke-control fans should be located higher in a building rather than at lower floors to limit exposure/access to external vents. Vestibules at stairways with separate pressurization provide an additional layer of smoke control.

Communication System

A voice communication system facilitates the orderly control of occupants and evacuation of the danger area or the entire building. The system is typically zoned by floor, by stairwell, and by elevator bank for selective communication to building occupants.

Emergency communication can be enhanced by providing:

- Extra emergency phones separate from the telephone system, connected directly to a constantly supervised central station;

- In-building repeater system for police, fire, and EMS (Emergency
- Medical Services) radios; and

- Redundant or wireless fireman's communications in building.

Summary of Mechanical and Electrical System Design Guidelines:

1. Place all emergency functions away from high-risk areas in protected locations with restricted access.

2. Provide redundant and separated emergency functions.

3. Harden and/or provide physical buffer zones for the enclosures around emergency equipment, controls and wiring.

4. For egress routes, provide battery packs for exit signs, use non-slip phosphorescent treads, and double doors for mass evacuation.

5. Avoid using glass along perimeter egress routes or stairwells.

6. Place emergency functions away from structurally vulnerable areas such as transfer girders.

7. Place a transformer interior to building, if possible.

8. Provide access to the fire control center from the building exterior.

Chemical, Biological and Radiological Guidance

This section discusses three types of air-borne hazards.

1. A large exterior release originating some distance away from the building (includes delivery by aircraft).

2. A small localized exterior release at an air intake or other opening in the exterior envelope of the building.

3. A small interior release in a publicly accessible area, a major egress route, or other vulnerable area (e.g., lobby, mail room, delivery receiving).

Like explosive threats, chemical, biological and radiological (CBR) threats may be delivered externally or internally to the building. External ground-based threats may be released at a standoff distance from the building or may be delivered directly through an air intake or other opening. Interior threats may be delivered to accessible areas such as the lobby, mailroom, or loading dock, or they may be released into a secured area such as a primary egress route. This discussion is limited to air-borne hazards.

There may not be an official or obvious warning prior to a CBR event. While you should always follow any official warnings, the best defense is to be alert to signs of a release occurring near you. The air may be contaminated if you see a suspicious cloud or smoke near ground level, hear an air blast, smell strange odors, see birds or other small animals dying, or hear of more than one person complaining of eye, throat or skin irritation or convulsing.

Chemicals will typically cause problems within in seconds or minutes after exposure, but they can sometimes have delayed effects that will not appear for hours or days. Symptoms may include blurred or dimmed vision; eye, throat, or skin irritation; difficulty breathing; excess saliva; or nausea.

Biological and some radioactive contaminants typically will take days to weeks before symptoms appear, so listen for official information regarding symptoms.

With radioactive "dirty" bombs, the initial risk is from the explosion. Local responders may advise you to either shelter-in-place or evacuate. After the initial debris falls to the ground, leaving the area and washing will minimize your risk from the radiation.

Buildings provide a limited level of inherent protection against CBR threats. To some extent, the protection level is a function of how airtight the building is, but to a greater extent it is a function of the HVAC system's design and operating parameters. The objectives of protective building design as they relate to the CBR threat are first to make it difficult for the terrorist to successfully execute a CBR attack and second, to minimize the impact (e.g., life, health, property damage, loss of commerce) of an attack if it does occur.

Air intakes

Air intakes may be made less accessible by placing them as high as possible on the building exterior, with louvers flush with the exterior. All opportunities to reach air-intakes through climbing should be eliminated. Ideally, there is a vertical smooth surface from the ground level to the intake louvers, without such features as high shrubbery, low roofs, canopies, or sunshades, as these features can enable climbing and concealment. To prevent opportunities for a weapon to be lobbed into the intake, the intake louver should be ideally flush with the wall. Otherwise, a surface sloped at least 45 degrees away from the building and further protected through the use of metal mesh (a.k.a. bird screen) should be used. Finally, CCTV surveillance and enhanced security is recommended at intakes.

In addition to providing protection against an air-borne hazard delivered directly into the building, placing air-intakes high above ground provides protection against ground-based standoff threats because the concentration of the air-borne hazard diminishes somewhat with height. Because air-blast pressure decays with height, elevated air intakes also provide modest protection against explosion threats. Furthermore, many recognized sources of indoor air contaminants (e.g., vehicle exhaust, standing water, lawn chemicals, trash, and rodents) tend to be located near ground level. Thus, elevated air intakes are a recommended practice in general for providing healthy indoor air quality.

In the event that a particular air intake does not service an occupied area, it may not be necessary to elevate it above ground level. However, if the unoccupied area is within an otherwise occupied building, the intake should either be elevated or significant precautions (tightly sealed construction between unoccupied/occupied areas, unoccupied area maintained at negative pressure relative to occupied area) should be put in place to ensure that contaminants are unable to penetrate into the occupied area of the building.

Mechanical Areas

Another simple measure is to tightly restrict access to building mechanical areas (e.g., mechanical rooms, roofs, elevator equipment access). These areas provide access to equipment and systems (e.g., HVAC, elevator, building exhaust, and communication and control) that could be used or manipulated to assist in a CBR attack. Additional protection may be provided by including these areas in those monitored by electronic security and by eliminating elevator stops at the levels that house this equipment. For rooftop mechanical equipment, ways of restricting (or at least monitoring) access to the roof that do not violate fire codes should be pursued.

Return-Air Systems

Similar to the outdoor-air intake, HVAC return-air systems inside the building can be vulnerable to CBR attack. Buildings requiring public access have an increased vulnerability to such an attack. Design approaches that reduce this vulnerability include the use of ducted HVAC returns within public access areas and the careful placement of return-air louvers in secure locations not easily accessed by public occupants.

The second objective is to design to minimize the impact of an attack. For many buildings, especially those requiring public access, the ability to prevent a determined terrorist from initiating a CBR release will be a significant challenge. Compared to buildings in which campus security and internal access can be strictly controlled, public-access buildings may require a greater emphasis on mitigation. However, even private-access facilities can fall victim to an internal

CBR release, whether through a security lapse or perhaps a delivered product (mail, package, equipment, or food).

Lobbies, Loading Docks, and Mail Sorting Areas

Vulnerable internal areas where airborne hazards may be brought into the building should be strategically located. These include lobbies, loading docks, and mail sorting areas. Where possible, place these functions outside of the footprint of the main building. When incorporated into the main building, these areas should be physically separated from other areas by floor-to-roof walls. Additionally, these areas should be maintained under negative pressure relative to the rest of the building, but at positive-to-neutral pressure relative to the outdoors. To assist in maintaining the desired pressure relationship, necessary openings (doors, windows, etc.) between secure and vulnerable areas should be equipped with sealing windows and doors, and wall openings due to ductwork, utilities, and other penetrations should be sealed. Where entries into vulnerable areas are frequent, the use of airlocks or vestibules may be necessary to maintain the desired pressure differentials.
Ductwork that travels through vulnerable areas should be sealed. Ideally, these areas should have separate air-handling units to isolate the hazard. Alternatively, the conditioned air supply to these areas may come from a central unit as long as exhaust/return air from these areas is not allowed to mix into other portions of the building. In addition, emergency exhaust fans that can be activated upon internal CBR release within the vulnerable area will help to purge the hazard from the building and minimize its migration into other areas. Care must be taken that the discharge point for the exhaust system is not co-located with expected egress routes. Consideration should also be given to filtering this exhaust with High Efficiency Particulate Air (HEPA) filtration. For entrance lobbies that contain a security screening location, it is recommended that an airlock or vestibule be provided between the secured and unsecured areas.

Zoning of HVAC Systems

Large buildings usually have multiple HVAC (heating, ventilation, air-conditioning) zones, each zone with its own air-handling unit and duct system. In practice, these zones are not completely separated if they are on the same floor. Air circulates among zones through plenum returns, hallways, atria, and doorways that are normally left open. Depending upon the HVAC design and operation, airflow between zones on different floors can also occur through the intentional use of shared air-return/supply systems and through air migrations via stairs and elevator shafts.

Isolating the separate HVAC zones minimizes the potential spread of an airborne hazard within a building, reducing the number of people potentially exposed if there is an internal release. Zone separation also provides limited benefit against an external release, as it increases internal resistance to air movement produced by wind forces and chimney effect, thus reducing the rate of infiltration. In essence, isolating zones divides the building into separate environments, limiting the effects of a single release to an isolated portion of the building. Isolation of zones requires full-height walls between each zone and the adjacent zones and hallway doors.

Another recommendation is to isolate the return system (i.e., no shared returns). Strategically locate return air grills in easily observable locations and preferably in areas with reduced public access.

Both centralized and decentralized shutdown capabilities are advantageous. To quickly shut down all HVAC systems at once in the event of an external threat, a single-switch control is recommended for all air-exchange fans (includes bathroom, kitchen, and other exhaust sources). In the event of a localized internal release, redundant decentralized shutdown capability is also recommended. Controls should be placed in a location easily accessed by the facility manager, security, or emergency response personnel. Duplicative and separated control systems will add an increased degree of protection. Further protection may be achieved by placing low-leakage automatic dampers on air intakes and exhaust fans that do not already have back-draft dampers.

Positive Pressurization

Traditional good engineering practice for HVAC design strives to achieve a slight overpressure of 5-12 Pa (.02-inch-.05-inch w.g.) within the building environment, relative to the outdoors. This design practice is intended to reduce uncontrolled infiltration into the building. When combined with effective filtration, this practice will also provide enhanced protection against external releases of CBR aerosols.

Using off-the-shelf technology (e.g., HEPA), manually triggered augmentation systems can be put into place to over-pressure critical zones to intentionally impact routes of contaminant migration and/or to provide safe havens for sheltering-in-place. For egress routes, positive-pressurization is also recommended, unless of course, the CBR source is placed within the egress route. Design parameters for such systems will depend upon many factors specific to the building and critical zone in question. Care must be taken that efforts to obtain a desired pressure relationship within one zone, will not put occupants in another zone at increased risk. Lastly, the supply air used to pressurize the critical space must be appropriately filtered (see filtration discussion below) or originate from a non-contaminated source in order to be beneficial.

Air tightness

To limit the infiltration of contaminants from outside the building into the building envelope, building construction should be made as airtight as possible. Tight construction practices (weatherization techniques, tightly sealing windows, doors, wall construction, continuous vapor barriers, sealing interface between wall and window/door frames) will also help to maintain the desired pressure relationships between HVAC zones. To ensure that the construction of the building has been performed correctly, building commissioning is recommended throughout the construction process and prior to taking ownership to observe construction practices and to identify potential airflow trouble spots (cracks, seams, joints, and pores in the building envelope and along the lines separating unsecured from secured space) before they are covered with finish materials.

Filtration Systems

To offer effective protection, filtration systems should be specific to the particular contaminant's physical state and size. Chemical vapor/gas filtration (a.k.a. air cleaning) is currently a very expensive task (high initial and recurring costs) with a limited number of design professionals experienced in its implementation. Specific expertise should be sought if chemical filtration is desired. Possible application of the air cleaning approach to collective protection zones (with emergency activation) can assist in significantly reducing the cost though the protection is limited to the reduced size of the zone.

Most "traditional" HVAC filtration systems focus on aerosol type contaminants. The CBR threats in this category include radioactive "dirty bombs", bio-aerosols, and some chemical threats. Riot-control agents and low-volatility nerve agents, for example, are generally distributed in aerosol form; however, a vapor component of these chemical agents could pass through a filtration system. HEPA filtration is currently considered adequate by most professionals to achieve sufficient protection from CBR particulates and aerosols. However, HEPA filtration systems generally have a higher acquisition cost than traditional HVAC filters and they cause larger pressure drops within the HVAC system, resulting in increased energy requirements to maintain the same design airflow rate. Due to recent improvements in filter media development, significant improvements in aerosol filtration can be achieved at relatively minimal increases in initial and operating costs. Also important is that incremental increases in filtration efficiency will generally provide incremental increases in protection from the aerosol contaminant.

In 1999, the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) released Standard 52.2-1999. This standard provides a system for rating filters that quantifies filtration efficiency in different particle size ranges to provide a composite efficiency value named the Minimum Efficiency Reporting Value (MERV). MERV ratings range between 1 and 20 with a higher MERV indicating a more efficient filter. Using the MERV rating table, a desired filter efficiency may be selected according to the size of the contaminant under consideration. For example, a filter with a MERV of 13 or more will provide a 90% or greater reduction of most CBR aerosols (generally considered to be at least 1-3 um in size or larger) within the filtered air stream with much lower acquisition and maintenance costs than HEPA filtration.

Efficiency of filtration systems is not the only concern. Air can become filtered only if it actually passes through the filter. Thus, filter-rack design, gasketing, and good quality filter sources should all play a role in minimizing bypass around the filter. The use of return-air filtration systems and the strategic location of supply and return systems should also be carefully employed to maximize effective ventilation and filtration rates.

Detection Systems

Beyond the measures discussed above, there is the option of using detection systems as part of the protective design package. In general, affordable, timely, and practical detection systems specific to all CBR agents are not yet available. However, for aerosol contaminants, nonspecific detection equipment can be employed to activate response actions should a sudden spike in aerosol concentration of a specific size range be detected. If the spike were detected in an outdoor intake for example, this could trigger possible response options such as damper closure, system shutdown, bypass to alternate air intake, or rerouting the air through a special bank of filters. Such protective actions could occur until an investigation was performed by trained personnel (i.e., check with adjacent alarms, and review security tape covering outdoor air intake). Unless foul play was discovered, the entire process could be completed within 10 minutes or less and without alarming occupants. The initial cost of such a system is relatively modest (depending upon the number of detectors and response options incorporated into the design), but the maintenance requirements are relatively high. Similar monitoring systems could be employed to trigger appropriate responses in high-threat areas such as mailrooms, shipping/receiving areas, or entrance lobbies. The approach could also be expanded to incorporate some of the newer chemical detection technologies, though the low threshold requirements may generate a substantial number of false positives. As technology progresses, detector availability and specificity should continue to expand into the general marketplace.

It is recognized that at this time, detection systems are not appropriate for many buildings. Consider using higher-efficiency filtration systems initially and design HVAC systems so that detection systems can be easily integrated into the HVAC control package at a later date.

Emergency Response Using Fire/HVAC Control Center

Certain operations that are managed at the Fire Control Center can play a protective role in the response to a CBR incident. Examples of such operations and how they could be used are given below.

- Purge fans. These can be used to purge an interior CBR release or to reduce indoor contaminant concentrations following building exposure to an external CBR source. (Note: In practice, some jurisdictions may recommend purging for chemical and radiological contaminants but not for biological contaminants, which may be communicable and/or medically treatable.)

- Communication Systems. Building communication systems that allow specific instructions to be addressed to occupants in specific zones of the building can play a significant role in directing occupant response to either an internal or external release.

- Pressurization Fans. These provide two functions. First, the ability to override and deactivate specific positive-pressure zones may be beneficial in the event that a known CBR source is placed into such an area. Second, areas designated for positive pressurization (generally for smoke protection) may also become beneficial havens for protection from internal and external CBR releases, if they are supplied by appropriately filtered air.

- HVAC Controls. The ability to simultaneous and individually manipulate operation of all HVAC and exhaust equipment from a single location may be very useful during a CBR event. Individuals empowered to operate such controls must be trained in their use. The provision of simple floor-by-floor schematics showing equipment locations and the locations of supply and return louvers will aid the utility of this control option.

- Elevator Controls. Depending upon their design and operation, the ability to recall elevators to the ground floor may assist in reducing contaminant migration during a CBR event.

Summary of Chemical, Biological and Radiological Design Guidelines:

1. Place air intakes servicing occupied areas as high as practically possible (minimum of 12 feet above the ground).

2. Restrict access to critical equipment.

3. Isolate separate HVAC zones and return air systems.

4. Isolate HVAC supply and return systems in unsecured areas.

5. Physically isolate unsecured areas form secured areas.

6. Use positive pressurization of primary egress routes, sage havens and other critical areas.

7. Commission building throughout construction and prior to taking occupancy.

8. Provide redundant, easily accessible shutdown capabilities.

9. For higher levels of protection, consider using contaminant-specific filtration and detection systems.

10. Incorporate fast-acting, low-leaking dampers.

11. Filter both return air and outdoor air for publicly accessible buildings.

12. Select filter efficiencies based upon contaminant size. Use reputable filter media installed into tight-fitting, gasketed and secure filter racks.

13. For higher threat areas (mail room, receiving, reception/screening lobby)

    - Preferably locate these areas outside the main building foot-print.
    - Provide separate HVAC, with isolated returns capable of 100% exhaust.
    - Operate these areas at negative pressure relative to secure portions of the building.
    - Use air-tight construction, vestibules and air locks if there is high traffic flow.
    - Consider installation of an emergency exhaust fan to be activated upon suspected internal CBR release.

14. Lock, secure, access-log and control mechanical rooms.

15. In public access areas, use air diffusers and return grills that are secure or under security observation.

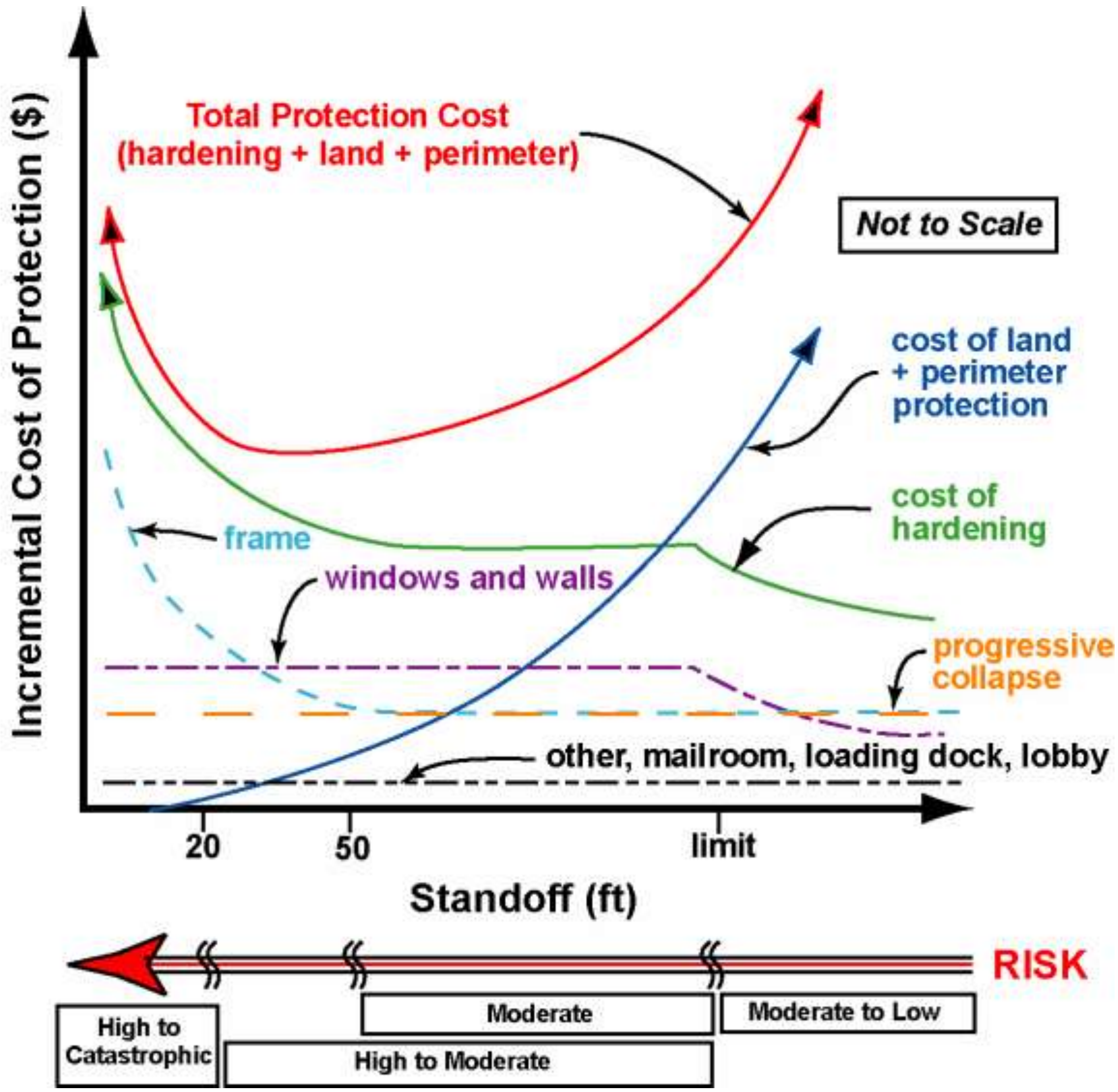
16. Zone the building communication system so that it is capable of delivering explicit instructions and has back-up power.

17. Create safe zones using enhanced filtration, tight construction, emergency power, dedicated communication systems and appropriate supplies (food, water, first aid and personal-protective equipment).

Cost of Various Designs

Though it is difficult to assign costs to various upgrade measures because they vary based on the site specific design, some generalizations can be made (see Figure below). Below is a list of enhancements arranged in order from most expensive to least expensive.

1. Hardening of unsecured areas
2. Measures to prevent progressive collapse
3. Exterior window and wall enhancements



References:

1. http://www.dhs.gov/xlibrary/assets/st/st-bips-06.pdf
2. http://www.wbdg.org/design/secure_safe.php
3. http://www.fema.gov/media-library/assets/documents/2150 (Download Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings)
4. DOJ, Vulnerability Assessment of Federal Building, June 28, 1995
5. NIOSH, Guidance for Filtration and Air-Cleaning Systems to Protect Building Environments from Airborne Chemical, Biological, or Radiological Attacks.
6. UFC 4-010-01, Unified Facilities Criteria, DoD Minimum Antiterrorism Standards for Buildings, 8 October 2003.
7. GSA, Alternate Path Analysis & Design Guidelines for Progressive Collapse Resistance, October 24, 2013.

