CHAPTER 58

CHEMICAL, BIOLOGICAL, RADIOLOGICAL, AND EXPLOSIVE INCIDENTS

THIS chapter considers chemical, biological, radiological, and explosive (CBRE) incidents that do not cause major structural damage to a building or its infrastructure. It is not intended to be used for design or development of life safety systems or procedures, or for protection of personnel during an incident; rather, it offers descriptions of some CBRE incidents and their associated effects on buildings, building equipment, and occupants, and offers general guidelines for how to deal with their effects on building infrastructure. Since September 11, 2001, more published information has been available about procedures for preventing, mitigating, and remediating terrorist or other CBRE incidents. ASHRAE's (2003a) *Report of Presidential Ad Hoc Committee for Building Health and Safety under Extraordinary Incidents* discusses many aspects of buildings, building infrastructure, and measures that can both reduce the threat and/or damage from such incidents. Several departments of the U.S. federal government, including the Federal Emergency Management Agency (FEMA), Department of Homeland Security (DHS), National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control (CDC), and Department of Defense (DOD), have produced reports and guidelines for dealing with terrorist threats to buildings (see the Bibliography). Emphasis is generally on actions to reduce the potential harm to building occupants, both by reducing the threat and by instituting procedures that reduce the hazard during an incident.

In almost any case of a terrorist event affecting a building, its infrastructure, or its occupants, the affected building and its immediate surroundings are likely to be in police or military control for several days (or longer) after the event. During this period, the role of the building(s) owner or physical plant staff is to assist in controlling or remediating the affected areas through their knowledge of the building and its infrastructure systems. Assessment of damage or remaining danger to the building or personnel is difficult, particularly with chemical, biological, and radiological events, in which the contaminating agent often is invisible and is only revealed through adverse health effects. As such, there are no specific guidelines for how or when a building can be brought back online and readied for occupancy; each event is unique. Any preparation or response protocol for CBRE incidents internal or external to the facility should be designed to consider the specifics of the building and its occupants. It is impossible to provide general guidelines for incidents that are so unpredictable and potentially so devastating. This chapter attempts to shed light on some of the possible effects to buildings, their systems, and their occupants, which may aid in the development of a more specific protocol in line with a particular facility's needs.

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CHEMICAL INCIDENTS

A chemical incident is defined as the accidental or intentional release of a gaseous or vaporous compound into breathable air. Releases of toxic liquids, solids, or powders are not addressed in this chapter. A release may occur inside or outside a building, and may be of short duration (e.g., from a broken container, an accidental valve opening, or a terrorist incident) or sustained (e.g., from a leaking storage tank or broken supply line). Descriptions of classes of and individual air contaminants, including chemicals, are found in Chapter 12 of the 2005 *ASHRAE Handbook—Fundamentals*, and removal techniques are covered in Chapter 25 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment* and Chapter 45 of this volume. Discussions in this chapter are limited to chemicals that are considered acutely toxic or corrosive, and present immediate danger to building occupants or systems.

Industrial buildings, where harmful chemicals may be used routinely, are likely at higher risk for internal chemical incidents than a typical commercial building, but, because of training, established procedures, and experienced personnel, they are also likely to be more prepared to handle an incident. Most commercial buildings, except for some government and high-profile buildings, do not have procedures in place for handling a chemical incident. A terrorist chemical event on a typical commercial building adds new difficulties, because details of the release are not known until long after the incident, and affected buildings and occupants are generally caught off guard, with little or no procedure in place for handling the event.

Chemical substances that can cause physical distress when introduced into breathable air are numerous; this chapter addresses only gaseous or vaporous compounds, and of those, addresses only two groups (1) those specifically known as chemical agents (in terms of warfare/terrorist activities) that might be intentionally introduced into a building's environment, and (2) a few common industrial gaseous substances that might accidentally be introduced into a building HVAC system through external or internal release, thus requiring HVAC or facility remediation of some kind. The purpose of this section is to address buildings that have no expectation of an accidental chemical release, based on the activities performed within the facility, as opposed to those of surrounding, related facilities (e.g., industrial facilities that have their own response plans). For control of airborne gases and vapors that are used as part of the building's normal operation, such as in laboratories or industrial processes, see Chapter 25 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment* and any of the application-specific chapters in this volume.

TYPES OF CHEMICAL AGENTS

Intentional contamination of facilities and their HVAC systems (and thus very ready dispersion to occupants) with gaseous or vaporous chemical substances has become a real concern. Chemical agents are classified by the U.S. Army *Fact Sheets* either as toxic or incapacitating. Toxic chemical agents include nerve, blister, lung-damaging, and blood agents. Any of these agents may be introduced in sufficient quantity so as to injure building occupants and, in the process, compromise the building's HVAC system. Irritating agents (e.g., tear gas), which cause temporary trauma through reflexive action but are not generally lethal, are not considered by the U.S. military to be chemical agents.

Incapacitating Agents

Incapacitating agents are defined by the U.S. DOD as chemical agents that produce temporary physiological or mental effects, or both, that make individuals unable to make a concerted effort to perform their assigned duties. In occupational medicine, *incapacitation* generally means *disability*, and denotes the inability to perform a task because of a quantifiable physical or mental impairment. Thus, by definition, any of the chemical warfare agents may incapacitate a victim; however, by the military definition, incapacitation refers to impairments that are temporary and nonlethal, and does not include low-dose "lethal" agents. Incapacitating agents may cause symptoms that persist for hours to days, but are temporary and recoverable even without treatment. Common incapacitating agents include

- 3-quinuclidinyl benzilate (BZ)
- Cannabinols
- Phenothiazines
- Fentanyls
- Central nervous system stimulants [e.g., d-lysergic acid diethyl amide (LSD)]

These agents act by either depressing or stimulating the central nervous system (CNS). Symptoms of poisoning by these agents include confusion, disorientation, restlessness, dizziness, staggering, or vomiting. Some may cause dryness of mouth, elevated temperature, pupil dilation, slurred/nonsensical speech, inappropriate behavior, and hallucinations. If several personnel exhibit any such behavior, it is prudent to move outside the building, because these agents are usually delivered by smoke-producing munitions or aerosols and are introduced through the respiratory system.

Irritants

The sole purpose of irritants, which include tear gas, riot control agents, and lachrimators, is to produce immediate discomfort and eye closure, thus rendering the victim incapable of fighting or resisting. Irritants cause eye discomfort, and some may cause vomiting; all are usually introduced to an environment as a gas. Police forces use them for crowd control. They were used before World War I, and, during the war, they were the first chemical agents used, well before better-known agents such as chlorine, phosgene, and mustard gas.

Tear gas (CS) and chloroacetophenone (CN; sold in diluted form as a protective spray) are by far the most important pulmonary irritants. Capsaicin (methyl vanillyl nonenamide) is the active ingredient in pepper spray, also called OC (oleoresin capsicum). Pepper spray has, to some extent, replaced CN as a personal protective agent, with less dangerous effects. As its common name implies, the active ingredient is the burning agent in pepper plant fruits.

Although CS and CN are the most important agents in this class, several others require mention. Chloropicrin (PS) and bromobenzenecyanide (CA) were developed before World War I. Both largely have been replaced, because they were too lethal for their intended effects but not lethal enough to compete with the more effective blistering and nerve agents. PS still is used occasionally as a soil sterilant or grain disinfectant.

Toxic Chemical Agents

Nerve Agents. Nerve agents are among the deadliest of chemical agents and may produce symptoms rapidly. Some nerve agents include

- VX
- Tabun (GA)
- Sarin (GB)
- Soman (GD)
- Cyclosarin (GF)

Nerve agents may be absorbed through any body surface (skin, eyes, respiratory) or ingested. Symptoms of nerve agent poisoning include

- Sweating and/or muscular twitching
- Pupil contraction, eye pain, or blurred vision
- Headache, pain
- Weakness
- Nausea, vomiting (particularly in ingestion)
- Mucous secretions in respiratory pathways, nose, or throat
- Wheezing, coughing
- Severe exposure: convulsions, vomiting, red pinpoint eyes, unconsciousness, or respiratory failure

Mild exposure to nerve agents may cause anxiety, restlessness, and giddiness. Further exposure results in the listed symptoms and/or memory impairment, slowed reactions, or difficulty in concentration. Moderate exposure, if diagnosed and monitored, shows abnormalities in electroencephalograms (EEGs) as well as the symptoms listed. Reactions to nerve agents are immediate (i.e., within minutes of exposure). Recovery from nerve agent exposure is slow, usually days, and susceptibility to the agent is increased for months afterward.

Nerve agents are liquids at room temperature. However, some are highly volatile and therefore would be easy to introduce as vapors through an HVAC system. Others have a relatively low volatility but can be introduced as droplets or vapor by mechanical means. Those that are highly volatile are generally not persistent (i.e., disperse quickly) unless thickened with various chemicals to make them persistent. VX, for example, is naturally persistent (with a relatively low volatility) and would require intense cleanup were it to be introduced to a building. For the most part, these agents are moderately soluble in water and highly soluble in lipids. They are rapidly inactivated by strong alkalis and chlorinating compounds, which are used in the decontamination/neutralization of these agents.

If nerve agents are suspected, evacuate the facility immediately. Because many nerve agents are (or can be made) persistent and dose is accumulative, evacuation is necessary. A facility must be decontaminated if exposed to nerve agents.

Blister Agents. Blister agents (vesicants) include the well-known mustard gas. These agents are generally used as warfare agents meant to degrade fighting efficiency rather than to kill. They are usually thickened to make them persistent and contaminate surfaces, but may be introduced as a gas or vapor. Vesicants result in burns and blisters to the skin, eyes, and/or respiratory tract. Types include

- Sulfur mustard (H and HD)
- Nitrogen mustards (HN)
- Lewisite (L)
- Halogenated oximes [e.g., phosgene oxime (CX)]

The most likely routes of exposure are inhalation, dermal contact, and ocular contact. Depending on the particular vesicant, clinical effects may occur immediately (as with phosgene oxime or lewisite) or may be delayed for 2 to 24 h (as with mustards). Blister agents must be cleaned from the skin and membranes immediately to lessen their effects. Persons exposed to blister agents must be handled so as not contaminate those helping them. Evacuation is necessary, and contaminated people should be kept outdoors to prevent accumulation of the vesicant in a confined space. Effects of exposure include

- Mild to severe conjunctivitis, possibly progressing to ulceration
- Lesions on skin; burns
- Itching
- Pain (immediate with exposure to lewisite)
- Respiratory damage (in small doses may take time to appear as bronchitis, etc.)

Vesicants are, for the most part, soluble in nonaqueous solvents, not in water. They are more dangerous as liquids, because the degree to which they cause health problems is related to their concentration on body surfaces. In general, they have high vapor pressures and thus are easily vaporized in a confined space. Decontamination of exposed surfaces is needed.

Lung-Damaging Agents. Lung-damaging (choking) agents are those that primarily attack lung tissue, causing pulmonary edema. Examples include

- Phosgene (CG)
- Diphosgene (DP)
- Chlorine
- Chloropicrin (PS)

As choking agents, most of these agents (except for diphosgene) exist as gases at room temperature and pressure, and are thus easily spread through ventilation systems. Exposure symptoms include

- Choking sensations, coughing
- Tightness in chest
- Nausea, vomiting
- Headache

Because these agents are gaseous, they will disperse. They all have specific odors; for example, CG smells like fresh mown hay. Thorough ventilation of contaminated areas is necessary. Choking agent gases typically are heavier than air, and thus tend to accumulate in low-lying areas.

Blood Agents. Blood agents, also known as cyanogens, interfere with the absorption and use of oxygen at the cellular level, and thus are usually introduced through the respiratory system. Examples include hydrogen cyanide (AC) and cyanogen chloride (CK). These agents are highly volatile and gaseous at temperatures over 70°F. They therefore dissipate quickly in air, especially hydrogen cyanide, which is light; cyanogen chloride is heavier than air and tends to collect in low places. These two blood agents have different symptoms. Symptoms of exposure to AC include

- Faint odor of almonds
- Internal hemorrhaging
- Pink skin color
- Highly toxic, high concentrations can cause immediate death

CK symptoms include

- Intense irritation to the lungs and eyes
- Coughing
- Tightness in chest
- Dizziness
- Unconsciousness
- Respiratory failure

Because these agents are not persistent, thorough ventilation should dissipate the gases.

Other HVAC-Compromising Gases and Vapors

Accidental contamination of facility HVAC systems by gaseous or vaporous chemical substances has been a real concern for years, mainly because of the extensive production, use, and transport of large quantities of hazardous materials for manufacturing purposes. Intentional contamination of a facility could be accomplished with chemicals other than the specific chemical agents discussed previously. Contamination internal to a building should result in immediate evacuation. However, external contamination might entail evacuation to a more distant location or shelter in place (i.e., do not evacuate). Contamination from an incident in the immediate vicinity of (but external to) a facility might require shutdown of the facility's HVAC system for a short period of time. For instance, a large corrosive spill nearby might necessitate staying in a building for protection while transportation is arranged (if not available immediately). This might occur at a school where children would be more susceptible to injury upon exiting the building, having no way to evacuate a safe distance. Because the situations and possibilities are so varied, this discussion is limited to some more typical scenarios.

Toxic Gases. The most common toxic gas that might threaten a facility and its personnel is carbon monoxide (CO), which is colorless, odorless, and tasteless. Carbon monoxide is produced by incomplete combustion of fossil fuels (gas, oil, coal, wood) used in boilers, engines, oil burners, gas fires, water heaters, solid-fuel appliances, and open fires. Dangerous amounts of CO can accumulate when, as a result of poor installation, poor maintenance, or failure, an appliance's fuel is not burned properly, or when rooms are poorly ventilated and the carbon monoxide is unable to escape. Because CO has no smell, taste, or color, it is important to have good ventilation, maintain all appliances regularly, and have reliable detector alarms installed to give both a visual and audible warning in case of a dangerous build-up of CO. Scenarios involving toxic gases usually entail evacuation to a safe distance. HVAC systems normally require cleaning using clean purge air the through the ventilation distribution system.

Corrosive Substances. Corrosive gases and vapors encompass a large class of materials. A few are purely gaseous in nature at room conditions, but some vapors result from the vapor pressure created by a liquid (or solid) presence. Some examples of corrosive gases and vapors are given in Table 1.

Corrosive gases and vapors are hazardous to all parts of the body, although some organs (e.g., eyes, respiratory tract) are particularly sensitive. The magnitude of the effect is related to the solubility of the material in body fluids. Highly soluble gases (e.g., ammonia, hydrogen chloride) cause severe nose and throat irritation, whereas lower-solubility substances (e.g., nitrogen dioxide, phosgene, sulfur dioxide) can penetrate deep into the lungs. Exposed skin may also be at risk for irritation or burns at higher concentrations or longer-term exposures. For some substances, warnings such as odor or eye, nose, or respiratory tract irritation may be inadequate. Accidents involving corrosive substances inside or outside a building require cleanup and decontamination of the facility's HVAC system and other equipment, because of the substances' persistence. In some cases, physical damage to a building's infrastructure may result from exposure to corrosives (e.g., etching of metal surfaces, which can lead to holes in ducting, and compromised wiring). Building codes outline methods of design and installation for mechanical and electrical systems in corrosive environments (NFPA 2005), but in buildings that are not classified as such, and thus are not constructed

Table 1 Corrosive Gases and Vapors

Corrosive Gases	Corrosive Acidic Vapors	Corrosive Basic Vapors
Hydrogen cyanide	Hydrochloric acid	Sodium hydroxide
Ammonia	Sulfuric acid	Ammonium hydroxide
Sulfur dioxide	Nitric acid	Caustic soda
Chlorine	Hydrofluoric acid	Potassium hydroxide
Hydrogen bromide	Acetic acid	Other hydroxides
Boron trichloride	Other acids	
Monomethylamine		
Phosphorus pentafluoride		

accordingly, systems may be damaged when exposed to corrosive chemicals. In such a case, the building and its systems should be thoroughly inspected and tested before reoccupation.

BIOLOGICAL INCIDENTS

Biological incidents involve the intentional or accidental release of unwanted bioaerosols and/or biocontaminants in or around a building, such that the building's integrity or usefulness is compromised. Bioaerosols are airborne particulates derived from living organisms and include living microorganisms, viruses, spores, and toxins derived from remnants or fragments of living tissue. Bioaerosols are in the air, both indoors and outdoors, and their presence mostly goes unnoticed except for seasonal allergies or an occasional cold. There is an evolved balance between the types and levels of bioaerosols in the ambient air and the animals who breathe that air. That balance can be disturbed locally by the purposeful or accidental release of a bioaerosol in or around a building. Unfortunately, bioaerosols are difficult to detect and identify in real time, because identification generally involves DNA analysis or other skilled analytical techniques. As a consequence, bioaerosols may be fully distributed in a building hours or days before anything is detected, much less identified, and the first sign of an incident may be symptoms of personnel.

There are hundreds of known bioaerosols that are pathogenic to humans to varying degrees. These include the spore-forming bacteria *Bacillus anthracis* (commonly known as anthrax), *Variola spp.* (the virus that causes smallpox), the bacteria *Yersinia pestis* (cause of bubonic plague), and many others. Human susceptibility varies by microorganism, and is gaged by several dose measures:

- **ID_{50}, mean infectious dose**, is the number of microorganisms or bioaerosol particles that causes 50% of an exposed population to be infected.
- **LD_{50}, mean lethal dose**, is the number of microorganisms or bioaerosol particles that causes death in 50% of an exposed population.

A summary of potential bioaerosol weapon agents is given in Table 2 along with ID_{50} and LD_{50} values. A more comprehensive list can be found in Kowalski (2003). More detailed descriptions of bioaerosols, their health effects, and methods of measurement can be found in most epidemiology texts. *Bioaerosols: Assessment and Control*, from the American Conference of Governmental Industrial Hygienists (ACGIH 1999), is a recommended starting point for quantitative determination of bioaerosol levels. General information on bioaerosols, their health effects, and their removal from building airstreams is found in Chapters 9 and 12 of the 2005 *ASHRAE Handbook—Fundamentals*, as well as Chapter 24 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*.

The primary threat to buildings from airborne biological incidents is adverse health effects to building occupants. Once an event happens, there is an immediate danger to building occupants from the initial dose, but there is also the risk of prolonged exposure from contaminated surfaces and reaerosolization of the agent. Depending on the agent, the prolonged exposure risk may dissipate quickly if the pathogenic organism has a short life outside of a host, or it may remain indefinitely until the contaminating agent is fully removed. Anthrax, which is a spore-forming bacterium, falls into this later category because it can lie dormant in many environments for long periods of time, only to come out of dormancy when exposed to a proper host. Excluding incidents of extreme mold growth [which is not covered in this chapter; see, e.g., ASHRAE (2003b) for information], biological incidents present no real threat to the integrity of building equipment; however, building equipment may play an important role in both distribution and possible removal of air contaminants. Remediation after an incident is likely to involve comprehensive cleaning of building equipment (particularly air-handling equipment), and may require removal and replacement of contaminated systems. Techniques for remediating contaminated equipment include surface cleaning with bleach or alcohol solutions, treatment with ultraviolet (UV) light, and volume gaseous treatments with ozone, hydrogen peroxide, or gas plasma. New technologies and procedures are under development, particularly since the anthrax events of 2001 in the United States. See the Bibliography and Online Resources for sources of information on the latest developments in remediation technology.

It is important to determine as much as possible about a release, whether purposeful or accidental, as rapidly as possible. It may be more difficult to completely assess the nature of a purposeful release, because it may contain more than one pathogenic agent, with different incubation periods, and the release may have taken place in several locations. Accidental releases are more likely to be a single pathogen at a single location, and the release is more likely to have been known to occur.

Biological pathogens have been weaponized to enable delivery in a variety of forms. Effective delivery of bioagents to a large population is difficult because of the need to get relatively large doses to large numbers of people. Dilution of contaminants in ambient air is rapid, and very large numbers of organisms are required to produce lethal concentrations. The confines of a building and controlled air exchanges rates can help maintain concentrations of agents for longer periods of time than would occur in outdoor air. However, filtration and real-time killing mechanisms in building air-handling systems can remove or render ineffective airborne bioaerosols. Engineering requirements for design of filtration or other techniques for treating indoor air are addressed more fully in other publications [e.g., NIOSH (2003)]. Information is rapidly evolving; for the latest, consult the most recent versions of publications on building protection.

Table 2 Limited List of Human Pathogenic Microorganisms

Bioaerosol	Incubation Period, Days	ID_{50}, Organisms	LD_{50}, Organisms
Bacillus anthracis (anthrax)	2 to 3	10,000	28,000
Ebolavirus spp. (Ebola)	14 to 21	10	Low
Francisella tularensis (tularemia)	1 to 14	10	Low
Hantavirus (Hanta)	14 to 30	N/A	N/A
Variola spp. (smallpox)	12	N/A	N/A
Yersinia pestis (bubonic plague)	2 to 6	N/A	N/A

RADIOLOGICAL INCIDENTS

The occurrence of a significant accidental or intentional radiological release to the environment is of low probability because there are limited locations where considerable amounts of radiological material reside. These sources include spent fuel or low-level radioactive waste (radwaste) storage facilities, nuclear generating stations, and weapons fabrication and storage facilities. These facilities are usually analyzed beforehand, as part of the construction licensing process, for postulated accidental releases of radiological material and the consequences to both on- and off-site personnel.

An intentional release of radiological material is most likely to be in the form of the deployment of a nuclear weapon or a radiological dispersal device (RDD), sometimes called a dirty bomb. It is normally assumed that a terrorist group is highly unlikely to possess and use conventional, sophisticated nuclear weapons because of the difficulties of obtaining or independently developing the necessary materials and technology. Development and deployment of an RDD, however, is considered viable because of its simplicity of design. RDDs combine conventional explosives and radioactive material, and are designed to scatter dangerous amounts of radioactive material over a general area. Terrorist use of RDDs also seems more likely because radiological materials used in medicine, agriculture, industry, and research are comparatively more obtainable than weapons-grade uranium or plutonium. A significant amount of the damage from an RDD would be from the initial blast. See the section on Explosive Incidents for design of HVAC system protection against blast effects.

RADIOACTIVE MATERIALS' EFFECTS AND SOURCES

Decay of radioactive materials produces energetic emissions (ionizing radiation) that can effect changes in human tissue cells. These energetic emissions are divided into **alpha** particles, **beta** particles, and **gamma/x-rays**. Alpha and beta radiation can only travel very short distances (several feet, maximum) and do not have enough energy to penetrate the outer layers of human skin; they are, however, a hazard if directly inhaled or ingested. Gamma and x-rays can travel long distances in air and can pass through the body, potentially exposing internal organs to significant damage, depending on the amount absorbed. The radiation effect on humans is usually measured in röntgen equivalent man (rem), the product of the absorbed dose and the biological efficiency of the radiation.

In developing an RDD, a significant quantity of radioactive material must first be collected. Some common radioactive materials currently used in industry include

- Colbalt-60 (Co-60), cesium-137 (Cs-137) and iridium-192 (Ir-192) are used in cancer therapy, industrial radiography and gages, food irradiation, oil well production, and medical implants. These are all considered gamma emitters.
- Strontium-90 (Sr-90) is used in the production of radioisotope thermoelectric generators (RTGs), which produce electricity for remote devices such as spacecraft. This is considered a beta emitter.
- Plutonium-238 (Pu-238) and americium-241 (Am-241) are used in oil well production, RTGs, and industrial gauges. These are considered alpha emitters.

RADIOLOGICAL DISPERSION

Dispersion may be by conventional explosives, using aircraft to disperse the material in the form of an aerosol or particulate, or simply placing a container of radioactive material within a confined area or facility. In most cases, a dirty bomb or other RDD would have localized effects (based on the strength of material used) ranging from less than a city block to several square miles. The area affected by the dispersion of the material is a function of various factors, including

- Meteorological conditions, including atmospheric stability and wind speed
- Local topography, location of buildings, and other landscape characteristics
- Amount and type of radioactive material dispersed
- Dispersal mechanism (e.g., particulate, aerosol)
- Physical and chemical form of the radioactive material (e.g., dispersal as fine particles versus heavier droplets or particulate)

Radioactive material released as either an aerosol or fine particulate in a plume spreads roughly at the speed and direction of the prevailing wind velocity. The conditions of atmospheric stability (sometimes referred to in terms of the Pasquill stability classification) also determine the fallout's overall spread and concentration. Atmospheric dispersion computer models are sometimes used to predict the spread, location, and concentration of a postulated radioactive plume. These analytical tools can be useful in providing early warning to residences and facilities projected to be in the affected fallout path.

RADIATION MONITORING

Radioactivity cannot be seen, smelled, or tasted by humans. However, in the United States, there are many radiation-monitoring programs available at the federal, state, and local level that can measure radiation levels and/or track the released radiation plume. There may be a local facility (e.g., a nuclear power plant) that can track radiological fallout in the affected area. State-level officials have access to various monitoring programs for their areas. These programs use current weather patterns and wind velocities to track radiological plumes and provide public warning. Depending on the severity of the release, the radioactive plume may travel several hundred miles or, more typically, be localized.

FACILITY RESPONSE

Physical safety of personnel should be of primary concern in responding to a radiological event. Time, distance, and shielding are the three most important aspects to minimizing the effects of human exposure to ionizing radiation. Shielding with stone, concrete, or other dense materials is usually not considered in the initial design of most commercial buildings. However, most facilities use these materials for structural strength (foundations and basements) or for fire protection in protective corridors and stairways. Procedures should be considered to instruct building occupants to immediately move to identified safe locations in the facility in the event of a known or suspected release. Limiting the time of exposure to a radiation field also helps reduce the total amount of exposure and subsequent health effects. Distance from the radiation source is the greatest factor in reducing the amount of direct (deep-dose) exposure, especially if the hazard is present for a considerable time period. The distance required to minimize this dose is usually small (several feet).

Perhaps the greatest potential hazard from the release of low-level radiological debris from an RDD is inhalation or ingestion. Health effects from ingested contamination particles that enter the body from breathing, cuts/abrasions, eating, or drinking can be more severe than external exposure, depending on the amount of material consumed. Individuals should be instructed to move to more isolated rooms, or areas within the facility that may be isolated or filtered from significant inleakage of contaminated air. Distribution of personal protection equipment should also be considered by the facility, depending on the risk assessment of a potential threat. If the release is determined to be internal, an organized evacuation should occur (consider developing evacuation procedures). Because evacuees may have become externally contaminated, an egress plan should be considered that includes a radiation detection monitoring procedure implemented either by internal personnel or by local emergency authorities. This procedure may include instruction to dispose of outer clothing and the use of showers to remove radioactive particles from body surfaces.

EXPLOSIVE INCIDENTS

Detonation of high explosives near a building generates pressures that act on all exposed surfaces. The magnitude of pressure depends on the size and shape of the charge, distance from the charge, and any intervening barriers. In addition to increased pressures, blasts may generate projectiles from either loose materials or fragments from damaged components. This section considers only loads that do not generate significant structural damage; it is assumed that, if the structure is severely damaged, continued operation of the HVAC systems is not crucial. Also, it is important to remember that life safety is the primary goal of all protective systems. This section deals strictly with HVAC equipment and systems, but any solutions must not compromise the safety of building occupants.

LOADING DESCRIPTION

Detonation of high explosives generates a pressure wave (blast wave) that propagates out from the explosion with decreasing veloc-

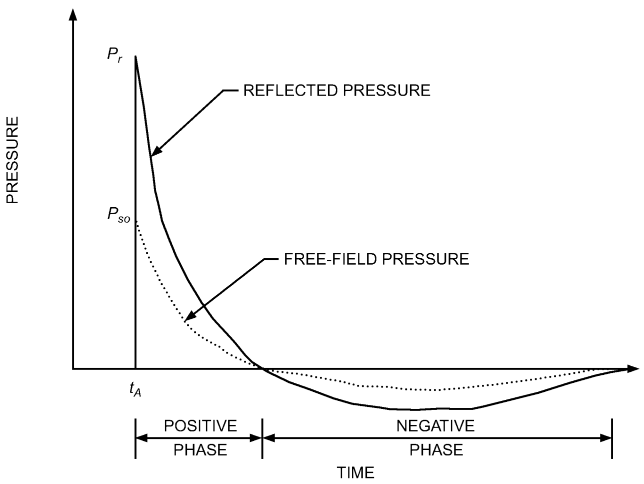

Fig. 1 Free-Field and Reflected Pressure Wave Pulses

ity. The free-field blast wave, far from any surfaces, is characterized by a rapid, almost instantaneous increase in pressure, followed by a gradual decay in pressure and a negative-pressure phase. A typical free-field blast overpressure, reaching the target at time t_A, is shown in Figure 1. When the blast wave impinges on a rigid surface, the pressure is reflected and magnified over the free-field values. Peak pressure varies inversely with the cube of the distance from the explosion. Intervening barriers may reduce the blast load, but quantifying the effect is difficult, and great care must be taken when determining the resulting loads.

Internal explosions can generate extremely large loads on HVAC equipment. In addition to short-duration reflected pressures generated by the explosion, a quasi-static pressure may develop, greatly increasing the impulse to which the equipment is exposed. The magnitude and duration of quasi-static loading is a function of room volume and vented area.

In addition to direct air blast, HVAC equipment in buildings subjected to explosions can experience large accelerations and relative displacements caused by the resulting structure motion. The structure responds to loads imposed both through the foundation (ground shock) and from the air blast (air shock). In general, accurately predicting the time history of motion in the building is extremely difficult. However, because structural design of equipment is based on peak loads, there is usually no need to determine the full time history. Methods are available for predicting the peak motion caused by a given event, including the frequency dependence of the response.

Blast loads can also enter the interior space of buildings through utility openings, even if the building shell is undamaged. The blast can damage the passageway itself, and can also build up pressure within the building and subsequently damage other equipment. Pressure build-up depends upon the opening area and volume of interior space, as well as the pressure differential.

Explosions can produce primary and secondary fragments that may damage equipment and piping. Primary fragments are generated from the explosive casing, whereas secondary fragments result from damage to the structure and nonstructural components (e.g., concrete spalling, glass breakage). Predictions of fragment size and velocity can be used to estimate damage to equipment, ducts, and piping.

DESIGN CONSIDERATIONS

The best protection from any explosive effects is to locate equipment in a nonvulnerable area. Assuming the exterior building shell is adequately designed, any interior room may be considered protected. Barrier walls can protect equipment that must be externally located, or the equipment can be positioned at sufficient distance from any possible blast location that pressures are reduced below damaging levels. In general, correctly locating equipment is the least expensive option for handling blast loads. Hardening the equipment, anchorage, and connection should be considered only after relocation has been eliminated as a possibility.

In addition to the direct air blast, equipment in a building subject to a blast experiences a support shock loading. Guidelines for the maximum shock that can be withstood by various equipment types are given in the ASHRAE Handbook (e.g., Chapter 54). Although general information can be obtained from these tables, it is important to realize that the data are several decades old and may not apply to modern HVAC equipment. If the shock is greater than the equipment's capacity, it may be possible to provide a shock isolation system to lower the demand. The isolation system works by decoupling horizontal motion of the support structure from that of the equipment. Note that this is different from typical equipment isolation applications, which are generally concerned with vertical vibrations of the equipment itself.

Although it has been stated that proper seismic design will also protect against blast loads, this is not generally true. The effect of blast loading on equipment has some similarities to that of seismic loads, but there are some key differences. Both loads generate horizontal and vertical forces that act on equipment. However, in both magnitude and distribution, seismic forces are proportional to equipment mass, whereas blast loads are proportional to the equipment surface area. The effect is essentially the same for some types of equipment, such as pumps, where the mass and surface area distributions are approximately identical. However, equipment covered by a sheet metal shell is loaded very differently. Seismic loads are applied directly to the heavy components within the shell, whereas blast loads are applied to the shell itself, with little or no load acting directly on the interior components. Thus, even equipment that has been seismically rated or certified needs additional investigation for blast resistance.

In contrast, anchorage design is identical for blast and seismic loads. Properly designed seismic anchorage for most equipment in moderate to high seismic zones is adequate for reasonable levels of blast loading. In either case, loads applied to equipment are used to determine shear and uplift loads on the anchorage that are checked against the allowable load for the specific attachment hardware. Although in reality the dynamic reactions from the resulting equipment motion are the actual anchorage force, for nonisolated equipment it is usually conservative to assume a static distribution of the maximum applied loads. This is not always the case for isolated equipment, because resonance of the load, equipment, and isolation system may produce dynamic forces well above those predicted from a static analysis.

When designing HVAC systems for blast load, it is important to remember that there are two types of failure. The first is a temporary loss of service, such as might be caused by tripping a breaker. The second, more serious case involves actual damage to the equipment or system. It is important to determine which scenario is important for the system, and design accordingly. Preventing temporary outages is, in general, much more expensive than preventing a catastrophic failure.

Exposed piping and ductwork are also subject to both pressure and fragment loading. Pressure loading can be carried through proper selection and spacing of supports. The flexure and shear capacities of the pipe or duct, and the capacity of the support, determine the spacing. Fragment effects are more difficult to analyze, because the exact size and velocity of any fragments is impossible to predict. The only way to fully protect against fragments is to locate the pipe or duct where fragment impact is not possible.

Openings in the building for HVAC or other purposes must also be designed for blast effects. HVAC systems can be damaged by pressure propagated through the opening or blockage of the opening. Grilles or louvers can be analytically designed to resist the blast load, preventing their blockage and allowing continued operation. Additionally, the pressure increase in ducts, and subsequently in interior rooms, can be calculated. Properly designed silencers may reduce pressure in ducts. The design of openings for blast resistance must also be closely coordinated with protection from chemical and biological agents.

HVAC SYSTEM DESIGN

The function of the facility's HVAC system(s) in response to a CBRE incident can be important in mitigating effects on occupants or, in the case of an internal event, on the surrounding environment. Design of the systems' outside air intake is critical in controlling the amount of dust, particulates, and foreign material entering the building. The following should be considered:

- Location of intakes above grade (out of normal human reach)
- Hiding or camouflaging intakes, securing with limited access from roof or other areas, and use of false intakes at lower building elevations
- Ability to isolate outside air intake or use an emergency standby system using high-efficiency particulate air (HEPA) and chemical filtration

Chapter 26 provides design and operational guidelines for HEPA and emergency filtration units.

HVAC systems with HEPA and chemically filtered protection should be designed with the following considerations:

- Transport of contamination may occur during initial stages of the event, if the HEPA filter protection system is a standby unit. Delay in response, either from manual or automatic actuation, may significantly affect overall filtration efficiency.
- The design should consider all building ventilation system intake and discharge flow paths, and airflow patterns in all operational modes should be thoroughly understood.
- Consider providing a clean safe room or area protected by HEPA/ emergency filtration.
- Consider operating the general facility at a positive pressure to outside ambient, to reduce unfiltered inleakage.
- Consider zoning the HVAC distribution system, to minimize cleanup costs and potential overall spread of contamination.
- Develop contingency plans/procedures for loss of ventilation or diminished HVAC system capabilities.

RISK EVALUATION

Probably the first activity a facility should consider in evaluating a CBRE incident is assessing the risk and required response. FEMA and other industry organizations have developed various guidance documents and software to assess the risk and appropriate response from both external and internal events. These evaluations consider the following major parameters:

Risk

- Identify potential high-value targets (e.g., nuclear power plants, museums, government buildings)
- Identify delivery systems
- Calculate risk and vulnerabilities
- Classify occupants
- Identify means to reduce vulnerability
- Consider providing personnel protective equipment (PPE)

Evacuation

- Establish safe egress path
- Categorize first responders
- Identify infrastructural support

Decontamination

- Provide PPE
- Implement recovery of HVAC systems
- Address cleanup, waste handling, and disposal (costs are generally high)

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ONLINE RESOURCES

U.S. Centers for Disease Control and Prevention: www.bt.cdc.gov/

U.S. Department of Homeland Security, Ready Web site: www.ready.gov/

Related Commercial Resources