Chapter X: Fire Protection Systems.

X.1.*Introduction.

X.1.1. *For further information see the following publications: NFPA Fire Protection Handbook, SFPE Handbook of Fire Protection Engineering.

X.2.*Passive Systems.

X.2.1.1. *For further information see the following publications: *NFPA 220, Standard on Types of Building Construction, 2006 Edition;* Buchanan, A.H. *Structural Design for Fire Safety*, John Wiley & SonsChickester, West Sussex, England, 2002.

X.2.1. Passive fire protection systems aim to protect occupants and/or a building through containment of fire and smoke. These systems are always present, and take no additional actions to activate in the event of a fire.

X.2.2. Compartmentation.

X.2.2.1. The common mode of fire spread in a compartmented building is through open doors, unenclosed stairways and shafts, unprotected penetrations through fire barriers, and non-fire-stopped combustible concealed spaces. Even in buildings of combustible construction, the common gypsum wallboard or plaster on lath protecting wood stud walls or wood joist floors provides a significant amount of resistance to a fully developed fire. When such barriers are properly constructed and maintained and have protected openings, they normally will contain fires of maximum expected severity in light-hazard occupancies. Even a properly designed, constructed, and maintained barrier will not reliably protect against fire spread indefinitely. Fire can also spread horizontally and vertically beyond the room or area of origin and through compartments or spaces that do not contain combustibles. Combustible surfaces on ceilings and walls of rooms, stairways, and corridors, which in and of themselves may not be capable of transmitting fire, will be heated and produce pyrolysis products. These products add to those of the main fire and increase the intensity and length of flames. Fire spread rarely occurs by heat transfer through floor/ceiling assemblies. Fire spread through floor/ceiling assemblies may occur in the later stages of fire development or through breaches of these assemblies.

X.2.2.1.1. (This is existing section 7.2.2.4.)

X.2.2.2. Fire Resistance.

X.2.2.2.1. The ability of the compartment boundaries to resist fire is dependent on their integrity and fire resistance rating.

X.2.2.2.2. Exterior walls, interior partitions, floors and floor/ceiling assemblies are components that define the functional layout of rooms and spaces in a building. In the normal functional use of a building, these components are used to provide privacy, security, protection from elements, and noise control. They can also provide fire protection by delaying or preventing heat and particles of combustion from spreading throughout the building.

X.2.2.2.3. **Walls.**

X.2.2.2.3.1. Non-load-bearing.

X.2.2.2.3.1.1. A non-load-bearing wall supports only limited loads in addition to its own weight. This type of wall can be used to separate rooms or compartments on a floor, and can also be called an interior partition. Its fire resistance requirement is designed to act as barrier to the spread of fire. These partitions can be used to protect areas of high hazard by having a higher fire resistance rating. These walls can be made of steel studs or wood studs covered in gypsum board or plaster, or masonry units, such as concrete block, structural clay, terra cotta, and gypsum block.

X.2.2.2.3.2. Load-bearing.

X.2.2.2.3.2.1. A bearing wall must be able to support significant vertical loads in addition to its own weight and are more common in older buildings than newer construction. These walls would be required to prevent structural collapse, as well as fire spread.

X.2.2.2.3.3. *Fire Walls.

X.2.2.2.3.3.1. Fire walls can be used to separate buildings and minimize the risk of fire spread between them. They can also be used within a building to subdivide it, effectively creating separate buildings.

X.2.2.2.3.3.2. Firewalls must remain stable for complete burnout on either side, as well as structural collapse of that side.

X.2.2.2.3.3.2.1. *For further information see the following publication: *NFPA 221, Standard for High Challenge Fire Walls, Fire Walls, and Fire Barrier Walls*.

X.2.2.2.4. Floor Assemblies.

X.2.2.2.4.1. Floor framing systems typically include not only the flooring assembly but also its supporting beams, girders or trusses.

X.2.2.2.4.2. Trusses

X.2.2.2.4.2.1. Where large areas must be column free or where special occupancy requirements may warrant, trusses may be used for purposes other than roof support.

X.2.2.2.5. Floor/Ceilings Assemblies.

X.2.2.2.5.1. Ceiling components are important elements in the performance of a fire-resistive floor/ceiling assembly. In the event of a fire within a room, the ceiling acts as a barrier to protect the structural framing above it. The degree of protection depends on the type of material, its installation and its completeness. Combustible ceilings or ceilings that do not remain in place when subjected to the pressures and temperatures of a fire do not provide a significant degree of protection. The membrane ceiling is one part of the floor/ceiling assembly. The entire assembly, acting together, provides the designated fire resistance.

X.2.2.2.5.2. If lighting fixtures and duct openings are included in membrane ceilings that are part of fire-rated assemblies, they both must be of suitable design and properly spaced, and they often require shielding to reduce heat transmission into the ceiling space.

X.2.2.2.6. Roof Assemblies.

X.2.2.2.6.1. The design and construction of roof framing follows the general pattern for floor framing systems—both must support vertical loads and distribute these loads to walls or columns. Roof loads are usually smaller than floor loads. In addition, architectural considerations may demand longer spans than floor framing, and the shape of the roof need not be flat.

X.2.2.2.6.2. **Roof Coverings.** In resistance to ignition and burning from exterior fire exposure, roof coverings range from combustible wood shingles with no fire-retardant treatment to built-up or prepared coverings that are effective against severe external fire exposure. Well-designed roof coverings can protect buildings from exposure fires and reduce the likelihood of fire spread from one building to another.

X.2.2.2.6.3. **Roof Deck Insulations and Vapor Barriers.** Even if a roof assembly is noncombustible, it may be insulated or covered with combustible materials that can have a significant effect on fire spread and growth. Metal deck roof assemblies are divided into two classes: those that will not contribute significantly to an interior fire and those that could produce sufficient heat release to allow a self-propagating fire on the underside of an unprotected deck.

X.2.2.2.7. **Corridors.** Corridors can be separated from other areas to provide a means of escape for the building occupants, as well as separating rooms or occupancies.

X.2.2.2.8. **Concealed Spaces.**

X.2.2.2.8.1. Concealed and other interstitial spaces can be found in most buildings. These spaces can create increased rates of fire spread and prolonged fire duration. Both of these factors aggravate the damage expected to be encountered.

X.2.2.2.8.2. Interstitial spaces in a high-rise building are generally associated with the space between the building frame and interior walls and the exterior façade, and with spaces between ceilings and the bottom face to the floor or deck above. These spaces may not have fire stops, the lack of which aids in the horizontal and vertical spread of fire. Those spaces provided with fire stops should be examined to determine the type and effectiveness of the installation.

X.2.2.2.8.3. Fire investigators should consider the impact of concealed spaces when they conduct a fire investigation. Failure to consider the effects of fire travel through concealed spaces may lead to misreading the fire patterns. Care must be taken when examining areas such as attics, roofs and lowered ceilings in rooms that can conceal fire and smoke until the fire is out of control.

X.2.2.2.8.4. **Fire Blocking Protection.** Fire blocking are barriers used to restrict spread of fire in concealed spaces. These barriers are normally noncombustible, but can also be combustible, such as the use of thick pieces of lumber. The materials should also have a large enough melting point that it will remain in place under fire exposure. Commonly used fire blocking materials are gypsum board, sheet metal, plaster, brick, cement grout, mineral fiber insulation, and ceramic fiberboards.

X.2.2.3. *Openings.

X.2.2.3.1. A common reason for failure of compartmentation to contain a fire is due to openings in the compartment boundaries.

X.2.2.3.2. For a compartment boundary to remain effective, the number and size of openings may be limited, and there may be requirements for protection of these openings.

X.2.2.3.3. Fire doors, windows and shutters are the most widely used and accepted means of protecting openings in fire-resistive walls. Suitability of these closures is determined through tests by recognized testing laboratories.

X.2.2.3.3.1. *For further information see the following publication: *Standard for Fire Doors and Other Opening Protectives*.

X.2.2.3.4. *Doors.

X.2.2.3.4.1. Fire doors are rated according to the duration of fire exposure and optionally, the temperature rise on the unexposed surface after 30 minutes. Doors rated for fire duration are rated as 4 hour, 3 hour, 1 ½ hour, 45 minute, 30 minute, and 20 minute. Doors with 4 or 3 hour ratings typically are in wall separating buildings or dividing buildings into different fire areas. Doors with 1 ½ hour ratings are used in 2 hour rated enclosures or in exterior walls that can be subjected to severe fire exposures from outside the building. Doors with 1 hour ratings typically protect vertical openings in buildings, such as stairs, shafts, and exit enclosures. Doors with 45 minute ratings are used in room partitions and walls around some hazardous areas, as well as into building corridors which have enclosure walls rated for 1 hour. They may also be used in exterior walls subject to a moderate or light fire exposure from outside the building.

X.2.2.3.4.2. In addition to the individual doors ratings, doors can be placed in series to increase the rating of the opening, which will be the sum of the ratings of each of the doors.

X.2.2.3.4.3. Fire doors are typically fitted with closers that cause the door to close automatically, helping to prevent smoke and fire spread. The most common failure mode of fire doors observed in actual fires was not closing. This has occurred because of lack of maintenance; physical damage to the closer, door, guides, or tracks; blockage in the doorway; and other faults. Reliable fire door performance cannot be ensured unless doorways are kept clear and doors maintained in operating condition.

X.2.2.3.4.3.1. *For further information see the following publication: *NFPA 252, Standard Methods of Fire Tests of Door Assemblies; NFPA 80,*

X.2.2.3.5. *Windows.

X.2.2.3.5.1. When glass is heated, it goes through a series of phases, softening or melting at temperatures of 600-800°C. It can also crack or break when exposed to thermal shock at lower temperatures, due to differential temperatures within the glass or because of expansion of the surrounding flame or possibly due to fast cooling during fire suppression or decay.

X.2.2.3.5.2. Glazing materials are available for use in fire-rated doors, windows, and walls; they are used as vision panels in fire doors and as windows in fire-rated corridor walls. In addition, they are frequently used in smoke-stop barriers and to enclose open stairways in older buildings.

X.2.2.3.5.3. Fire rated glazing can consist of wired glass, which allows heat to be more evenly distributed through the glass sheet, or special fire protection-rated clear glass and transparent ceramics.

X.2.2.3.5.4. *Damage to glass caused by a fire is further discussed in Section 6.2.13.

X.2.2.3.6. **Firestop Protection**. Firestops are materials used to fill in gaps around penetrations in walls or ceilings. These materials protect penetrations of fire-rated walls and floors. The space around the penetration is filled with a noncombustible material, such as cement grout, mineral wool, or cement plaster. Lack of firestop systems or improperly protected openings can lead to severe fires.

X.2.2.3.7. **Ducts.**

X.2.2.3.7.1. Air-handling ducts are potential paths for fire spread in buildings. Some ducts are required to be provided with fire resistance, which can be achieved through the design of the duct construction or insulation with additional materials.

X.2.2.3.7.2. Ducts passing through barriers can cause a reduction in the fire resistance of the barrier. This can be prevented by placing a fire damper inside the duct where it passes through the barrier, which can also control smoke movement. The dampers are designed to close automatically.

X.2.2.3.7.3. When there is a severe fire on one side of a wall penetrated by a duct, the collapsing duct on the hot side of the wall may cause damage to the wall itself, reducing the fire resistance. To prevent such damage, the fire damper should be firmly attached to the wall and the duct should be constructed with joints which allow the duct to pull away from the damper, leaving the damper intact as part of the wall.

X.2.3. *Fire Protection of Structural Elements

X.2.3.1.1. *For further information see the following publications: *ASCE/SEI/SFPE 29-05 Standard Calculation Method for Structural Fire Protection*.

X.2.3.1. Structural Steel.

X.2.3.1.1. Unprotected structural steel loses its strength at high temperatures and must be protected from exposure to heat produced by building fires. This protection insulates the steel from the heat.

X.2.3.1.2. **Encasement**.

X.2.3.1.2.1. Structural steel members may be encased in poured concrete. This allows for excellent durability, yet is expensive, bulky and time-consuming.

X.2.3.1.2.2. Steel members may also be encased with board systems, providing a barrier between a fire and the structural member, decreasing the amount of heat transmitted. The most common materials used in board systems are calcium silicate and gypsum.

X.2.3.1.3. Surface Treatment.

X.2.3.1.3.1. Surface treatments applied directly to the member are also capable of insulating a member.

X.2.3.1.3.2. **Spray-On Fireproofing.** Low density sprayed-on cementitious and mineral fiber coatings are widely used. The protection is excellent if applied correctly, however it can be accidentally scraped off or damaged during construction or renovations. The initial application must be monitored, and maintenance conducted to ensure the fireproofing is effective.

X.2.3.1.3.3. **Intumescent Coatings.** Intumescent coatings have been used to increase the fire endurance of structural steel. These coatings appear as paints on the steel member during normal conditions, but intumesce, or swell, when heated, forming an insulation around the steel.

X.2.3.1.4. **Filling.** Some less common forms protection of structural steel elements are filling hollow members. The filler acts as a heat sink to reduce the temperature increase in the steel element. Some materials may also be load-bearing, carrying some of the load that is no longer carried by the steel element. The most common filling materials are concrete or water.

X.2.3.2. **Reinforced Concrete.** Concrete is often used as a protective coating for other materials, as well as a primary load-bearing structural material, and often performs well in a fire situation. The concrete mix can affect the fire resistance of the concrete, including the concrete's density, aggregates, and moisture content. The actual design of the concrete member is also important, such as the cover over steel reinforcing bars and restraint conditions.

X.2.3.3. **Wood.** Depending on its form, wood may or may not provide reasonable structural integrity in a fire. The important factors that influence fire resistance are the physical size and moisture content of the members. Fire-retardant treatments may also be used to delay ignition and retard combustion.

X.2.4. **Impact on Investigation.**

X.2.4.1. An investigator needs to determine whether a passive fire protection measure failed, and if it did so, why this occurred. This damage could have been due to problems with the design of the system, including the initial design not being adequate for the expected fire severity, or the fire hazard changing over the lifetime of the structure and not appropriately modifying the fire protection. There may have also been problems with the initial construction or application of the protection, or improper maintenance, such as allowing breaches in compartment walls or damage to applied coatings. Analysis of the damage to systems may also aid in the development of the fire's growth history.

X.2.4.2. Analysis of Structural Damage. Knowledge of a structural element's response to fire can aid in determining the severity of a fire through an examination of the damage done to the structural element. The response of a structural element's protection can also aid in determination of fire severity. If a fire severity is known, it may be possible to use this in the elimination of fire origin or causes.

X.3. Active Systems.

X.3.3. Active fire protection systems consist of those that take an additional action to activate in the event of a fire.

X.3.4. *Fire Detection.

X.3.4.1.1. *For further information see the following publication: *NFPA 72 National Fire Alarm Code*.

X.3.4.1. Types of Devices.

X.3.4.1.1. Initiating Devices

X.3.4.1.1.1. Spot-Type. A device in which the detecting element is concentrated at a particular location.

X.3.4.1.1.2. Line-Type. A device in which detection is continuous along a path.

X.3.4.1.1.3. Video. Video-based systems use video cameras to detect smoke or flames in protected areas. The images are processed by computer software.

X.3.4.1.2. Smoke Detectors vs. Smoke Alarms. Smoke detectors are sensing devices that, when activated, signal remote alarm panels and notification devices to go into alarm and perform certain actions. The detector itself does not sound. Smoke alarms are devices that contain both the sensing components as well as a notification component inside the same housing. These are often used in residences.

X.3.4.1.3. Notification devices. Notification devices sound an audible, visual, or tactile alarm to alert occupants to the fire.

X.3.4.1.3.1. Audible. Audible notification appliances are the most common method for signaling a fire alarm or other emergency condition in a building or area. Performance is defined as the ability to alert and convey information and is based on the device rating, or sound pressure level at a fixed distance in a special room, and net sound pressure level produced throughout all of the building or area served by the system.

X.3.4.1.3.1.1. The frequency of the alarm signal is also a design factor. Typically, high-pitched sounds (high frequency) are heard better than low frequency, bass, sounds. Research has shown, however, that low frequency sounds are better for awakening occupants and for notifying the hard-of-hearing.

X.3.4.1.3.1.2. Audible notification devices must be designed to be louder than the ambient noise in a space. This can be accomplished through sound pressure level or frequency of the alarm signal. An alarm signal can be designed at lower sound pressure levels by using frequency bands that are not occupied by ambient noise. To hear a fire alarm signal above the ambient noise, it does not have to be louder than all of the component frequencies added together; it just has to be louder than one. As long as one of the alarm signal’s frequency bands is taller than the corresponding ambient noise level, you will hear the signal, even if the total broadband sound pressure level of the noise is greater than the total broadband sound pressure level of the signal. This concept is most often used in settings which have a high level of ambient noise, such as manufacturing plants.

X.3.4.1.3.2. **Visual.** Visible fire alarm notification appliances are often intended only to augment audible appliances. However, when it is expected that hearing-impaired persons may be in the protected area or when ambient noise levels are high, visible appliances may be the primary means of occupant notification that a fire emergency exists. The only types of visual appliances currently addressed by *NFPA 72* are strobe lights.

X.3.4.1.3.3. ***Tactile.** Tactile notification appliances alert by the sense of touch or vibration. These are used in conjunction with audible or visible, or both, notification devices. They are often used as bed shakers to awaken those who are hearing impaired.

X.3.4.1.3.3.1. *For further information see the following publication: *ANSI/UL 1971, Standard for Signaling Devices for the Hearing Impaired*

X.3.4.2. Heat Detection.

X.3.4.2.1. A heat detector is a fire detector that detects either an abnormally high temperature or rate of temperature rise, or both. Heat detectors are considered very reliable and having a low rate of false alarm. They are often used in small confined spaces, where a fire will cause a rapid increase in temperature.

X.3.4.2.2. Fixed-Temperature Detector. A device that responds when it's operating element becomes heated to a predetermined level.

X.3.4.2.3. Rate-Compensated Detector. A device that responds when the temperature of the air surrounding the device reaches a predetermined level, regardless of the rate of temperature rise. These devices can be considered to be a sensitive fixed-temperature detector.

X.3.4.2.4. Rate-of-Rise Detector. A device that responds when the temperature rises at a rate exceeding a predetermined value, regardless of the actual air temperature. It is important that these detectors are not placed in areas where high rates of heat rise are expected in normal operation, including commercial kitchens, laundries, dishwashing areas, or equipment repair facilities. These detectors will also not activate for a slowly developing fire.

X.3.4.2.5. **Combination Fixed-Temperature/Rate-of-Rise Detector.** A combination fixed-temperature/rate-of-rise detector contains more than one element that responds to fire, and can be designed to activate upon response from either element or both elements.

X.3.4.3. Smoke Detection.

X.3.4.3.1. A smoke detector will often detect fires more rapidly than a heat detector.

X.3.4.3.2. Ionization.

X.3.4.3.2.1. Ionization smoke detectors have a small amount of radioactive material that ionizes air in the sensing chamber, and permits a current flow through the air between two charged electrodes. When smoke particles enter the ionization area, they attach themselves to the ions and decrease the current flow, which when it decreases below a predetermined level, will cause the detector to activate.

X.3.4.3.2.2. Ionization smoke detectors respond to the number density of smoke particles, and generally provide a faster response to flaming fires, which produce large amounts of small particles.

X.3.4.3.3. Photoelectric.

X.3.4.3.3.1. Photoelectric smoke detectors operate by projecting a light beam through the air, with a transmitter and receiver, which will be affected by the smoke particles and can be monitored in two ways.

X.3.4.3.3.1.1. **Light-Scattering.** In a light-scattering photoelectric smoke detector, the transmitter will not line up with the receiver, and in normal operation, light will not fall on the receiver. When smoke particles enter a light path, scattering will occur, and light will be reflected onto the receiver, causing activation of the detector.

X.3.4.3.3.1.2. **Light-Obscuration.** In light obscuration photoelectric smoke detectors, smoke will obscure the beam, reducing the light reaching the photosensitive device and initiating the alarm.

X.3.4.3.3.2. Photoelectric smoke detectors respond to the optical density of smoke and generally respond faster to smoldering fires, which produce a large amount of visible size range smoke particles. They may also provide a better response than ionization detectors when the fire is not close, such as their use in ducts.

X.3.4.3.3.3. Photoelectric smoke detectors are also allowed in locations that could cause other types of detectors to sound nuisance alarms, such as near cooking appliances in kitchens.

X.3.4.3.4. **Combination/Algorithm-based Detectors.** Newer models of detectors have incorporated multiple types of detection systems to achieve greater sensitivity (early response) without sacrificing stability (increasing unwanted alarms). These devices can incorporate a thermal sensor with a smoke sensor or multiple smoke sensors (e.g. ion and photo).

X.3.4.3.5. Air-Sampling (Aspirated) Smoke Detectors.

X.3.4.3.5.1. An air sampling detector draws in air from the protected space and analyzes it for smoke particles.

X.3.4.3.5.2. These devices can have a very high sensitivity, providing early warning of fires. The sensor is connected to the protected area by a network of tubing or piping (with spaced intake ports), which draws air samples. This allows devices to be placed in sensitive areas, such as prisons or mental health facilities.

X.3.4.3.5.3. Filters are also included in the device to remove most dust particles and prevent false alarms that would occur in non-aspirating smoke detectors.

X.3.4.3.5.4. **Continuous Air-Sampling.** In this device the air is continuously sampled and monitored for smoke particles.

X.3.4.3.5.5. **Cloud Chamber Principle Air-Sampling.** In this device the relative humidity of the air sample is increased, and subjected to reduction in air pressure so it becomes supersaturated. If any smoke particles are present, they act as condensation nuclei for water droplets, and form a cloud in the sensing chamber, whose density is measured by the photoelectric light-scattering detector, which will respond if the threshold density is exceeded.

X.3.4.3.5.6. Spot-Type Aspirating. In this device the air is sampled once a minute by a small on-board fan with a replaceable filter whose status is verified every few hours. This device is especially useful in ordinarily dusty environments, such as stables, paper plants, cotton and textile mills, commercial laundries, food processing areas and so on.

X.3.4.3.6. **Projected Beam.** Projected beam detectors are the most common form of light obscuration photoelectric smoke detectors. A beam is projected across a large open space, such as an atrium, auditorium, or manufacturing area. This beam is equivalent to a row of spot-type smoke detectors along the beam path. A transmitter and receiver are installed at opposite ends of the area to be protected, with unobstructed views of each other. The range and mounting distance from the ceiling vary according to manufacturers.

X.3.4.3.7. **Duct.** Smoke detectors may be located in return and/or supply ducts of HVAC systems to prevent smoke from a fire spread throughout the building. When activated, these detectors will often cause the HVAC system to shut down or transition to smoke control mode.

X.3.4.4. **Radiant-Energy Detection.**

X.3.4.4.1. Radiant energy-sensing devices sense the radiant energy emitted as a by-product of the combustion reaction. They are divided into flame detectors and spark/ember detectors.

X.3.4.4.1.1. **Flame Detectors.** Flame detectors operate in the ultraviolet (UV) and/or infrared (IR) portion of the radiation wavelength spectrum. The wavelength is dependent on the defined fire under specific conditions, as different fuels can release radiation in different wavelengths.

X.3.4.4.1.2. **Spark/Ember Detectors.** Spark/ember detectors are installed to detect sparks or embers that could, if allowed to continue to burn, precipitate a much larger fire or explosion. Typical applications of these include ducts or conveyers to monitor fuel as it passes by.

X.3.4.4.2. In selecting a detector, the device's spectral response must be matched to the spectral emissions of the potential fire to be detected, as well as an analysis of sources of non-fire radiant energy in the area.

X.3.4.4.3. The size of fire that can be detected is a function of the distance between the detector and the radiant energy source. The sensitivity of a device varies according to manufacturer.

X.3.4.4.4. Placement of the detector is important, as these detectors are line-of-sight devices, so that no areas required to be protected are outside the field of view of at least one detector. Spacing is determinant on the overall protection objectives of the system, including the minimum fire size that must be detected and the required response time.

X.3.4.5. Additional Types of Detectors.

X.3.4.5.1. **Gas-Sensing.** Fires can produce several different gases as products of combustion, with the type and production rate dependent on the fuel composition, fire size, ventilation conditions and burning mode. Gas sensors can be used to detect the release of a particular chemical, or the ratio of chemicals, that will be expected in a fire scenario.

X.3.4.5.2. **CO Detectors.** Carbon monoxide detectors may also activate in a fire scenario, however they will be more delayed than detectors specifically designed for fires. They can be used, however, in situations where other types of fire detectors are not present.

X.3.4.6. **Installations Considerations.**

X.3.4.6.1. Detectors may be connected to additional building services, which will be affected upon activation of the detector. These can include HVAC control, door closers, suppression systems, or elevator controls.

X.3.4.6.2. **Placement**. Spot-type detectors are usually installed on the ceiling, with a specified distance away from the wall, or if their listing permits, on the wall. When there is possibility of mechanical damage, approved guards should be used to prevent degradation of the sensor performance. Spacing of detectors is also important to ensure all required areas are protected.

X.3.4.7. *Use of Detection Systems in Investigations.

X.3.4.7.1.1. *For further information see the following publication: Olenick, S.N., Roby, R.J., Klassen, M.S., Zhang, W., Sutula, J.A., Worrell, C., Wu, D., D'Souza, V., Ashley, E., DuBois, J., Torero, J.L., & Streit, L.A., "The Role of Smoke Detectors in Forensic Fire Investigation and

Reconstruction," presented to the International Symposium on Fire Investigation Science and Technology (ISFI), June 26-28, 2006.

X.3.4.7.1. When conducting an investigation, it is important that all fire protection systems, especially detectors and alarms, be analyzed. The examination of the detection system is important in determining if it functioned properly, and can assist in tracking the growth and spread of a fire. Device locations and conditions should be documented, including the height of wall-mounted devices or the distance of ceiling-mounted devices from walls.

X.3.4.7.2. **Operability.** It must be determined if the detector was operable, including checking whether the battery was properly in place and charged if it was a battery-powered device, or checking whether the power was properly connected if it was an AC-powered device. A "canned smoke" test may be used to check if the smoke-sensing system was operational, however this may cause a problem with obscuration of smoke deposits that could be used in further analysis of the device.

X.3.4.7.3. ***Analysis of Smoke Deposition.** In fire reconstruction, knowledge of whether a particular smoke detector sounded during the fire can be valuable. It may be of special interest if there were fatalities or injuries involved. Knowing whether a detector sounded can provide information as to when, or if, an occupant may have been alerted to a developing fire.

X.3.4.7.3.1. Determination of alarm sounding may be possible from interviews of witnesses or first responders; however, smoke detector horns can often be so thermally damaged that an alarm may not be able to be heard by the time rescue personnel arrive.

X.3.4.7.3.2. An analysis of the smoke deposition on the detector may also aid in determining if the alarm sounded. When the horn sounds, an acoustic field is created, causing soot particles to increase in size in the area of the horn and deposit preferentially on specific locations of the detector. Research has shown that the presence of this sonic deposition of agglomerated soot can be used to make a determination of whether the smoke detector sounded an alarm during the fire.

X.3.4.7.3.3. The color and consistency of these deposits will also aid in determining the type of fuel burned in a fire. Typically, the soot that will be deposited will be a black carbon-based material. However, if the fuel burned is polymeric, an orange tarry substance can be deposited. The mode of combustion also affects the composition of the soot pattern.

X.3.4.7.3.4. This deposition may potentially be assessed from a visual macroscopic inspection, but microscopic analyses may need to be performed. It is therefore vital that the fire investigator retain the smoke detector/alarm remains found in a fire scene.

X.3.4.7.3.5. *For further information see the following publications:

X.3.4.7.3.5.1. Worrell, C.L., Roby, R.J., Streit, L., and Torero, J.L., "Enhanced Deposition, Acoustic Agglomeration, and CHladni Figures in Smoke Detectors," *Fire Technology*, 37, 2001.

X.3.4.7.3.5.2. Worrell, C.L., Lynch, J.A., Jomaas, G., Roby, R.J., Streit, L., and Torero, J.L., "Effect of Smoke Source and Horn Configuration on Enhanced Deposition, Acoustic Agglomeration, and Chladni Figures in Smoke Detectors," *Fire Technology,* 39, 2003.

X.3.4.7.3.5.3. Phelan, P., An Investigation on Enhanced Soot Deposition on Smoke Alarm Horns, Master of Science Thesis, Worcester Polytechnic Institute, Worcester, MA, 2005.

X.3.4.7.3.5.4. Kennedy, K.C., Gorbett, G.E., and Kennedy, P.M., "A Fire Analysis Tool – Revisited: Acoustic Soot Agglomeration in Residential Smoke Alarms, " poster presentation, INTERFLAM, 2004.

X.3.4.7.3.5.5. Mealy, C.L., & Gottuk, D.T., "Full-Scale Validation Tests of a Forensic Methodology to Determine Smoke Alarm Response," *Fire Technology*, 47, 2011.

X.3.4.7.4. **Time to Activation.** It is important to determine the time the detector activated if it did operate, or what time it should have activated if it did not operate. The time to activation is dependent on the location of the detector, as well as the detector design itself. Lag time often must be included to account for the time for smoke to penetrate the detector housing and be sensed by the electronics.

X.3.4.7.5. ***Computer Modeling.** Use of computer models allows fire investigators to test origin and cause hypotheses, as well as the fire effects on the surrounding environment. Complex algorithms have been developed that allow for an accurate representation of smoke and heat transport, aiding in the determination of detector/alarm activation times.

X.3.4.7.5.1. Computer models will also inform the investigator of the length of time until untenable conditions are reached to determine if the detectors would provide adequate warning to victims.

X.3.4.7.5.2. *For further information see the following publications:

X.3.4.7.5.3. Cleary, T., Chernovsky, A., Grosshandler, W., and Anderson, M., "Particulate Entry Lag in Spot-Type Smoke Detectors," Proceedings of the Sixth International Symposium on Fire Safety Science, 1999.

X.3.4.7.5.4. Olenick, S.M., Zhang, W., Carpenter, D.J., Roby, R.J., & Klassen, S.M., "Verification and Validation of a Smoke Detector Activation Algorithm for the Fire Dynamics Simulator (FDS)", presented to the NFPA Fire Protection Research Foundation Fire Suppression and Detection Research Application Symposium, Orlando, January 2005.

X.3.4.7.6. **Determination of Fire Size.** It may be possible to use the activation or non-activation of detectors to determine the fire's size. The minimum fire size necessary to activate the system can be estimated. If the system did not activate, but was found to be properly designed and in working order, it may be possible to use this calculated fire size as the maximum fire size; whereas if the system did activate, a minimum fire size may be established. Knowing the maximum or minimum fire size can be an aid in determining the cause of the fire and means of its spread.

X.3.4.7.6.1. It must be noted, however, that all factors involved in the system and fire must be considered, including but not limited to the type of system, its placement with respect to the fire, the surrounding ventilation conditions, and the products generated by the fire. For example, an ionization smoke detector may be more sensitive to certain types of smoke than a photoelectric smoke detector causing each to activate at different times even when exposed to the same fire.

X.3.4.7.7. **Determination of Timeline.** If the detection system is connected to a monitored system, these records can be used to establish a timeline of the fire spread. In some cases, the specific location or zone of the first activating detector can be used to narrow down an area of origin, allowing an investigator to assess specific ignition sources in that area. Some systems provide only alarm data, and do not specify a particular zone. This information can be helpful in comparing the time of system activation to the time and observations of first arriving fire fighters or other witnesses, in assessment of the growth and spread of the fire.

X.3.4.7.7.1. Even if a time history of the systems' activations are not known, a map of the detectors activated can be used to generate a pattern of the fire spread throughout the building.

X.3.4.7.7.2. Accessing data from a smoke alarm system panel should only be completed by a trained and competent individual to prevent the data from being erased. The information should be collected before the panel is removed, as cutting the power may kill the memory.

X.3.4.7.7.3. Alarm system data may also be collected from a central/remote monitoring station if the system was continuously monitored. Information from past incidents can also be collected from these stations.

X.3.5. *Fire Alarms.

X.3.5.7.1. *For further information see the following reference: Bukowski, R.W. & Moore, W.D. Fire Alarm Signaling Systems, 2003; *NFPA 72 National Fire Alarm Code; NFPA 101 Life Safety Code.*

X.3.5.1. Types of Fire Alarm Systems

X.3.5.1.1. **Protected-Premises (Local) Systems.** Protected-premises (local) fire alarm systems are supervised systems that provide fire alarm and supervisory signals within a facility and produce a signal at the facility only. The main purpose of these systems is evacuation of the facility's occupants. The fire authorities are notified by someone present at the facility.

X.3.5.1.2. **Auxiliary Systems.** Auxiliary systems transmit alarm signals via a municipal fire alarm system, which will automatically call or notify a fire department following activation of an automatic or manual fire alarm.

X.3.5.1.3. **Monitored System**

X.3.5.1.3.1. A monitored system is one where alarm, supervisory or trouble signals are sent to a constantly monitored station. When an alarm signal is received the operators must take actions that are in accordance with NFPA 72, including notification of the public fire communication services.

X.3.5.1.3.2. Central Station. A supervising station that is listed for central station service and that also commonly provides less stringent supervising station services such as remote supervising services.

X.3.5.1.3.3. Proprietary Station. A supervising station under the same ownership as the protected premises fire alarm system(s) that it supervises (monitors) and to which alarm, supervisory, or trouble signals are received and where personnel are in attendance at all times to supervise operation and investigate signals.

X.3.5.1.3.4. Remote-Station. A supervising station to which alarm, supervisory or trouble signals or any combination of those signals emanating from protected premises fire alarm systems are received and where personnel are in attendance at all times to respond.

X.3.5.2. Types of Fire Alarm Signals

X.3.5.2.1. **Manual Fire Alarm Signals.** Manual fire alarm signals are initiated from manual fire alarm boxes located throughout the protected premises.

X.3.5.2.2. **Automatic Fire Alarm Signals**. Automatic alarms are typically initiated by detectors located within the protected premises.

X.3.5.3. Alarm Initiating Devices

X.3.5.3.1. Manual Fire Alarm Box Stations.

X.3.5.3.1.1. Noncoded or Coded. A coded station allows the location of the alarm box to be determined. A noncoded station will continue to actuate until the station is reset to normal.

X.3.5.3.1.2. **Pre-signal or General Alarm.** Presignal stations initially cause alarm signals to sound only in specific areas. An evacuation signal will sound upon actuation of a key switch on the station or control panel or after a predetermined amount of time has passed. A general alarm signal will sound evacuation signals immediately. Presignal stations are often used in locations where evacuation would be difficult or unsafe, such as hospitals, schools or prisons.

X.3.5.3.1.3. **Breakglass or Nonbreakglass.** A breakglass station requires an initial action of breaking a glass or other breakable element to actuate the device. Stations that do not require breaking an element are nonbreakglass stations.

X.3.5.3.1.4. Single Action or Double Action. A single-action station requires only one action by the user to initiate an alarm, such as breaking a glass or actuating a lever. A double-action station requires two actions to take place, such as breaking a glass and opening a door.

X.3.5.3.2. Automatic Fire Detectors

X.3.5.3.2.1. Automatic fire detectors will have an alarm built into the system. These are further discussed in Section X.3.2.

X.3.5.4. *Use of Alarm Systems in Investigation.

X.3.5.4.1.1. *For further information see the following publication: Olenick, S.N., Roby, R.J., Klassen, M.S., Zhang, W., Sutula, J.A., Worrell, C., Wu, D., D'Souza, V., Ashley, E., DuBois, J., Torero, J.L., & Streit, L.A., "The Role of Smoke Detectors in Forensic Fire Investigation and Reconstruction," presented to the International Symposium on Fire Investigation Science and Technology (ISFI), June 26-28, 2006.

X.3.5.4.1. ***Thermal Incapacitation.** Thermal damage to an alarm sounder will reduce or eliminate its ability to alert occupants. An analysis of the thermal damage can be made to determine the thermal environment of the alarm/sounder, such as temperatures reaching a certain level.

X.3.5.4.1.1. *Research has shown that the sound emitted from horns will be greatly diminished when the surrounding gas temperatures reach approximately 100°C ± 14°C; there will be complete failure at temperatures of approximately 119°C ± 17°C.

X.3.5.4.2. ***Alarm Effectiveness.** If it is determined that a smoke detector activated, yet sleeping occupants were not alerted, consideration must be made for the type of occupants. Studies have been conducted on the waking effectiveness of various subjects, including those hard of hearing, elderly, children, and those with impaired judgment.

X.3.5.4.2.1. *For further information see the following publications:

X.3.5.4.2.2. Ashley, A., DuBois, J., Klassen, M., and Roby, R., "Waking Effectiveness of Audible, Visual, and Vibratory Emergency Alarms Across Different Hearing Levels," Proceedings of the Eighth International Symposium on Fire Safety Science, 2005.

X.3.5.4.2.3. Bruck, D. "Non-Awakening in Children in Response to a Smoke Detector Alarm," *Fire Safety Journal*, 32, 1999.

X.3.5.4.2.4. Bruck, D. "The Effect of Alcohol Upon Response to Fire Alarm Signals in Sleeping Young Adults," *Proceedings of the 3rd International Conference on Human Behavior in Fire,* 2004.

X.3.5.4.2.5. Nober, E.H., Pierce, H., and Well, A. Waking Effectiveness of Household Smoke and Fire Detection Devices, NBS-GCR-83-439, 1983.

X.3.5.4.3. Determination of Timeline. Similar to centrally monitored detection systems (X.3.4.7.7), records of alarms can be used to establish a timeline of the fire spread and possibly narrow down the origin to a specific location or zone, as well as provide an analysis of fire spread. It can also be observed where manual alarms were activated, however this may be more indicative of the locations of building occupants and their escape routes than the actual location of the fire origin.

X.3.5.4.4. Impact on Human Behavior

X.3.5.4.4.1. The presence of active fire protection systems will have an impact on the behavior of the building occupants. Fire alarm systems are among the variables of built-in fire safety that may be critical to an individual's awareness of a fire. Research has shown that verbal, directive messages may be most effective in creating response, compared to alarm bells and sounders alone.

X.3.5.4.4.2. Prior false alarms and alarm system malfunctions may reduce the positive effect of having an alarm system in the building, because the occupants may not response appropriately to the alarm notification. Numerous false alarms reduce the occupants' appropriate responses to the alarm.

X.3.6. Fire Suppression Systems.

X.3.6.4. Extinguishment Mechanisms.

X.3.6.4.1. Fire suppression methods can use one or a combination of the mechanisms to extinguish or control a fire.

X.3.6.4.2. **Cooling: Heat Reduction.** Flaming combustion requires a high temperature in order for the chemical reactions to proceed. By reducing the amount of heat in the combustion zone, a fire can be controlled or extinguished.

X.3.6.4.3. **Smothering: Oxygen Deprivation.** The fire can be extinguished by reducing the amount of oxygen that is available to the fire.

X.3.6.4.4. Fuel Removal. Removing the fuel available can also extinguish a fire. This can be accomplished, for example, by diluting a flammable pool of liquid to the point where it is no longer flammable.

X.3.6.5. *Fire Suppression Agents.

X.3.6.5.1.1. *For further information see the following reference: Gagnon, R. Design of Special Hazard & Fire Alarm Systems, 1997.

X.3.6.5.1. When conducting an investigation, it is important to learn what methods and fire suppression agents were used to fight the fire. This can be used in the analysis of fire damage, which may have been influenced by the compatibility or incompatibility of the type of fire and suppression actions taken.

X.3.6.5.2. **Aqueous Agents**

X.3.6.5.2.1. Aqueous agents include water and water-based agents that include additives to enhance the effectiveness of water.

X.3.6.5.2.2. **Water.** Water is the most widely used extinguishing agent. This is due to its low cost, ready availability, and effectiveness in fighting most types of fires.

X.3.6.5.2.3. **Fire-Fighting Foam.** Fire-fighting foams are used in fixed and portable fire extinguishing systems, primarily to combat flammable and combustible liquid fuel fires. Foam is used to suppress liquid fuel vapors and cool the liquid surface. Foams vary in terms of their chemical makeup, which affects the required rate of application and appropriateness for use on particular liquid fuel hazards.

X.3.6.5.3. **Nonaqueous Agents.** Nonaqueous agents are agents in which water is not a component. These are useful in situations where water would not be appropriate or effective, such as when water would react with the item being extinguished (e.g. metal shavings) or would damage items being protected (e.g. electrical systems).

X.3.6.6. Types of Automatic Suppression Systems.

X.3.6.6.1. *Sprinkler Systems. Automatic sprinklers are thermosensitive devices designed to react at predetermined temperatures by automatically releasing a stream of water and distributing it in specified patterns and quantities over designated areas. The automatic distribution of water is intended to extinguish a fire or to prevent its spread in the event that the initial fire is out of reach of the sprinkler's discharge or is of a type that cannot be extinguished by water discharged from sprinklers. The water is fed to the sprinklers through a system of piping, ordinarily overhead, with the sprinklers placed at intervals along the pipes.

X.3.6.6.1.1.1. *For further information see the following publications: NFPA 13 Standard for the Installation of Sprinkler Systems; NFPA 72 National Fire Alarm Code.

X.3.6.6.1.1. System Types.

X.3.6.6.1.1.1. **Wet Pipe Systems.** Wet pipe systems contain water under pressure at all times and utilize a series of closed sprinklers. When a fire occurs and produces a sufficient amount of heat to activate one or more sprinklers, because an automatic water supply is mandated, water immediately discharges from the open sprinklers.

X.3.6.6.1.1.2. **Dry Pipe Systems.** The system piping contains no water prior to system activation but rather is charged with air or nitrogen under pressure. A dry pipe valve holds back the water supply and serves as the water/air interface. If a fire occurs and a sufficient amount of heat is generated, one or more sprinklers operate, causing a system air pressure to drop. Once the air pressure falls below a predetermined level, the dry pipe valve opens, allowing water to flow through the system to the open sprinklers.

X.3.6.6.1.1.3. **Preaction Systems.** This system is similar to a dry pipe system where a standard or single-interlock preaction system piping is charged with air under pressure rather than water. However the air pressure associated with preaction systems is generally less than that for dry pipe systems. The water supply is held back by means of a preaction valve. The system is equipped with a supplemental detection system. Operation of the detection system allows the preaction valve to automatically open and admit water into the pipe network. Water will not discharge from the system until a fire has generated a sufficient quantity of heat to cause operation of one or more sprinklers.

X.3.6.6.1.1.4. **Deluge Systems.** Deluge systems deliver large quantities of water over specified areas in a relatively short period of time. These systems are used to protect against rapidly growing and spreading fires. Sprinklers used in a deluge system do not contain thermally sensitive operating elements and are referred to as open sprinklers. A deluge valve controls the system water supply and is activated by a supplemental fire detection system. As water reaches each sprinkler in the system it is immediately discharged from the system.

X.3.6.6.1.2. System Components.

X.3.6.6.1.2.1. **Sprinklers.** Sprinklers must be listed and only new sprinklers are permitted for use. Various types of sprinklers are available on the worldwide market. Sprinkler characteristics include the K-factor (a description of the size and angle of the inlet of the sprinkler's orifice), temperature rating, and applied coatings (either required for effective operation or for aesthetic qualities). In addition to the design of the sprinkler head itself, there are also distinctions for the situating of the sprinkler which will affect the patterns of water discharge, such as recessed, flush-type, concealed, ornamental, dry pendant and dry upright sprinklers.

X.3.6.6.1.2.2. **Pipe and Tube.** A number of piping materials are acceptable for use in sprinkler systems, with steel, copper, and nonmetallic pipe materials currently addressed by NFPA 13. These pipe materials must meet certain pipe manufacturing standards, certain listing requirements, or both. Limiting the type of pipe that are acceptable for use will increase reliability of not only the system installation, but it will also ensure the integrity of the system piping during a fire. In addition to identifying the type of pipe materials that can be used, NFPA 13 also specifies how the pipe is to be joined.

X.3.6.6.1.2.3. **System Valves.** Automatic sprinkler systems are required to have at least one listed valve installed to allow for the system to be shut down. As a matter of course, sprinkler systems should never be shut down except when system modifications are being accomplished or during the time following a fire to allow for replacement of any sprinklers that operated. The types of valves used in a sprinkler system vary with the location of the valve in the water supply system or portion thereof.

X.3.6.6.2. ***Water Mist Systems.** Water mist systems are distribution systems connected to a water supply that is equipped with one or more nozzles capable of delivering water mist intended to control, suppress, or extinguish fires.

X.3.6.6.2.1. *For further information see the following publication: NFPA 750 *Standard on Water Mist Fire Protection Systems*.

X.3.6.6.3. Compartment Flooding. Compartment flooding methods fill a fire compartment with a gas that will cause extinguishment of the fire through creation of an atmosphere where flammable vapors will no longer burn.

X.3.6.6.3.1. Flooding Mechanisms.

X.3.6.6.3.1.1. A total flooding system has nozzles which inject the gases to create a uniform concentration throughout the enclosure. For this system to be effective, the enclosure's integrity must be intact to prevent gas leakage that could dilute the concentration and prevent control or extinguishment of the fire.

X.3.6.6.3.1.2. A local application flooding system has nozzles which are designed for specific locations to quickly extinguish all flames as quickly as possible. These systems require automatic detection to prevent a fire from growing to the size where it overwhelms the local system.

X.3.6.6.3.1.3. The two systems can be used together, where a local system provides fast knockdown of a fire, and total flooding provides extinguishment.

X.3.6.6.3.2. **Halon & Halon Replacement.** The original halocarbon agents designed, including Halon 1301, are no longer used, due to their impact on the environment, but a newer generation of agents can be used in compartment flooding applications. The gases are typically effective in lower volumes than other inert gases, as well as maintaining a tenable atmosphere for humans.

X.3.6.6.3.3. **Inert Gases.** The most common inert gas used in fire extinguishment is carbon dioxide, but nitrogen and steam are also used. However, the concentrations of carbon dioxide necessary to extinguish a fire will be detrimental to human health.

X.3.6.6.4. **Dry Chemical.** Dry chemicals, consisting of a fine powdered chemical, provide an alternative to carbon dioxide or halons for extinguishing a fire without using water. These chemicals act to suppress the flame of a fire, and the type of chemical used is dependent on the expected fire.

X.3.6.7. Use of Fire Suppression Systems in Investigation.

X.3.6.7.1. **Determination of Fire Size.** Automatic suppression systems can also be considered to act as automatic fire detectors and can provide a similar analysis of fire size as that with detectors (Section X.3.2.7.6). The design of the capacity of the suppression system and whether it could control the fire can also be used in determination of origin and cause.

X.3.6.7.2. Determination of Timeline. Similar to centrally monitored detection systems (X.3.2.7.7), records of activation of automatic fire suppression systems can be used to establish a timeline of the fire spread and possibly narrow down the origin to a specific location or zone, as well as provide an analysis of fire spread.

X.3.6.7.3. **Impact on Human Behavior.** The presence of automatic fire suppression systems, if known, may affect behavior. The effect may be positive or negative. A positive effect is that the increased margin of safety of such systems provides occupants of the involved structure more time to respond appropriately to the hazards presented by the incident. An example of a negative effect is possible decreased visibility caused by the discharge of the suppression agent, which may impede egress.

X.3.6.7.4. **Computer Modeling.** The use of computer models will aid in determining the activation of automatic suppression systems, as well as the impact on fire. The modeling of these systems is complex and specialized algorithms must be used for accurate analysis.

X.3.7. Design Considerations

X.3.7.6. **Placement.** Fire protection systems should be placed in a way that will allow them to remain effective. This includes ensuring that detectors are in a position where they would be able to detect a fire, and that suppression systems are able to extinguish or control a fire. Placement will be dependent on the layout of the protected premises, as well as the ventilation characteristics.

X.3.7.7. Capacity. The systems designed must have sufficient capacity to remain effective. This is especially true in the case of suppression systems, where calculations must be made on the expected capacity of the system and the likely fire scenarios.

X.3.7.8. Coverage.

X.3.7.8.1. Total (Complete) Coverage. Where a fire protection system covers all rooms, halls, storage areas, basements, attics, lofts, spaces above suspended ceilings, and other subdivisions and accessible spaces, as well as the inside of all closets, elevator shafts, enclosed stairways, dumbwaiter shafts, and chutes.

X.3.7.8.2. **Partial or Selective Coverage.** Where a fire protection system covers only a portion of the selected areas.

X.3.7.8.3. **Local Coverage.** Where a fire protection system protects a particular location only, such as a certain piece of equipment.

X.3.7.8.4. Knowing the amount of coverage of the fire protection system will aid the investigator in analyzing the amount of damage caused by the fire, as well as the fire spread patterns.