THIRD EDITION

FIRE PROTECTION SYSTEMS

A. Maurice Jones, Jr.

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A. Maurice Jones, Jr.
Supervisor, Fire Protection Systems
Alexandria Fire Department
Alexandria, Virginia

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18461-7

Production Credits
General Manager and Executive Publisher: Kimberly Brophy
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Composition: S4Carlisle Publishing Services
Cover Design: Scott Moden
Text Design: Scott Moden
Media Development Editor: Shannon Sheehan
Rights & Media Specialist: John Rusk
Cover Image (Title Page): Courtesy of A. Maurice Jones, Jr.
Printing and Binding: LSC Communications
Cover Printing: LSC Communications

Library of Congress Cataloging-in-Publication Data
Library of Congress Cataloging-in-Publication Data unavailable at time of printing.

Library of Congress Control Number: 2019911937

6048

Printed in the United States of America
24 23 22 21 20 10 9 8 7 6 5 4 3 2 1

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Control and Management Systems, Property Security, and Fire Protection Systems

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Currently, he is working with David Diamantes on the 4th edition of the Jones & Bartlett book *Principles of Fire Prevention* that will published in 2020.

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SECTION

1

Establishing the Relationship Between Fire Behavior, the Model Codes, and Fire Protection Systems

CHAPTER 1

Establishing the Relationship Between Fire Behavior, the Model Codes, and Fire Protection Systems

Basics of Fire Behavior

LEARNING OBJECTIVES

At the conclusion of this chapter, you will be able to:

- Describe the difference between fire and combustion.
- Identify and describe the elements of the fire triangle.
- Identify and describe the elements of the fire tetrahedron.
- List and describe the different types of fire.
- List and describe the different stages of fire.
- List and describe the mechanisms of heat transfer.
- List and describe the methods used to extinguish fires.
- List and describe the classes of fire and their relationship to extinguishing agents.

Case Study

On July 23, 2018, in Shasta County, California, the perfect environmental conditions were in place for a wildfire. The area was experiencing hot and dry conditions; there was abundant fuel and erratic wind. The only thing needed was a source of heat. That afternoon, it appears that source came from a trailer being towed that suffered a flat tire, causing sparks to emanate from the tire rim. The sparks came in contact with dry vegetation, and with the aid of the wind, the fire spread over 20,000 acres in the first 3 days. On July 26, the fire doubled in size to nearly 49,000 acres and became so intense that at one point, a deadly fire tornado raged for about 30 minutes. The massive growth that day was evident when the fire jumped what would usually be a natural fire break, the Sacramento River. With unlimited air, fuel, no geographical or other physical limitations, and the challenging topography that limited fire crew access to the area, the fire continued to burn for a number of weeks. Eventually, the fire spread into Trinity County, and over the 5 weeks from the start of the fire to containment, 229,651 acres burned, 1881 structures were damaged or destroyed, 11 people were injured, and 3 fire fighters and 5 civilians lost their lives. Damage estimates were over $1.6 billion with just under $159 million in suppression costs. At the time of the fire, the Shasta fire ranked as the sixth most destructive wildfire in California history.

That changed in November 2018 as fires in Butte and Ventura Counties surpassed the Shasta/Trinity fire with the Butte County fire becoming the most destructive and deadly wildfire in California history. The Butte fire destroyed 18,804 structures and killed 85 people. The Ventura fire became the seventh most destructive wildfire in California with 1,643 structures destroyed and three people killed. All of these incidents demonstrate how the most basic elements needed to start a fire—a heat source, abundant dry fuel, and unlimited air—can come together and, in no time, result in a devastating and life-altering event.

1. What impact does the public's desire to build at the urban/wildland interface have on the fire service's ability to deal with wildfires?
2. What effects do you think climate change and the environment have on wildland fires?
3. What type of planning, technology, and resources would help to reduce losses associated with wildland fires?
4. Should state or federal agencies attempt to enact legislation to restrict a developer's or landowner's right to build on property or require stricter development and building codes when building in the urban/wildland interface?
5. What role do you think the insurance industry plays in this discussion?

Sources: Modified from Cal Fire. *Carr Fire Incident Final Update 1/4/2019.* Sacramento, CA: California Department of Forestry and Fire Protection, 2019. Accessed January 6, 2019. http://cdfdata.fire.ca.gov/incidents/incidents_details_info?incident_id=2164;

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Introduction

Engineering and designing any **fire protection system** requires an understanding of fire behavior as it relates to the type and size of the **fire hazard** the system will protect. Most properties and structures have some level of associated fire hazard that could be negligible, moderate, or significant. When evaluating a fire hazard, several factors come into play, including occupancy and use conditions; the materials, products, and finishes involved in constructing a building; the quantity, arrangement, and type of items within the building; and the method of handling or storing the items that are present. Consideration of all these factors is critical in the hazard evaluation and design process when deciding on the type of fire protection system that will best protect the structure or hazard.

From the moment a building is built and occupied, but especially when buildings change owners or tenants, it is important to ensure that all fire protection systems in the building are adequate for the conditions of occupancy and use. Fire fighters performing familiarization drills in buildings must remain cognizant of the occupancy conditions, the types of hazards, the types of processes, and the quantities and types of materials in a property. If any of these conditions change, not only will the building's **preplan** and response protocol need updating, but the adequacy of the fire protection systems will need to be reevaluated. Warehouses are a good example to illustrate this point because it is not unusual for the contents and the storage method to change over time. When the contents and method of storing are changed, the fire hazard could greatly increase owing to a change in the **fuel load** that could render the fire protection system inadequate.

Although complacency about fire protection systems is typically not intentional, the condition and adequacy of these systems are commonly overlooked. Unfortunately, any failure to reevaluate a fire protection system based on the fire hazards and fuel loads present could result in property damage, property loss, injury, and possible loss of life.

To assess any fire hazard, a basic understanding of fire chemistry and fire dynamics is necessary. This information provides the firefighting community with the insight and understanding of fire behavior that form the basis for every manual fire attack undertaken by firefighting crews. It is not necessary to be a researcher or scientist to be a competent fire fighter, fire officer, or investigator, but understanding how and why fire occurs is essential. To extinguish a fire, it is critical to understand what sustains a fire.

There have been numerous research projects conducted and textbooks written that provide in-depth analysis and study documenting fire behavior, the combustion process, and the chemistry and physics of fire. In this chapter, the discussion focuses on some of the fundamental concepts related to the design of fire protection systems.

TIP

The fuel load (the amount of combustible and flammable materials within an area) is one of the factors that determine the hazard classification of a building.

Combustion and Fire

Most people never contemplate the chemical and physical circumstances that must come together to start a fire. When hearing the word **fire**, most people probably do not think about atoms and molecules in sustained chemical reactions or about **ignition**, **flammable limits**, **oxidation**, or **heat transfer**. Instead, some people might think about the fire used for cooking, warmth, and illumination in homes or businesses. This type of fire is managed by mechanical systems, controls, and safety mechanisms that regulate how much oxygen, fuel, and heat mix to operate such things as a gas oven, furnace, water heater, fireplace, lantern, or gasoline engine. Other people might think about uncontrolled flames burning a path of destruction and leaving behind extensive or total damage to a structure and property. Whatever the initial perception, the process that results in fire can be either beneficial when correctly managed or destructive when incorrectly managed.

It is important to distinguish between the terms **combustion** and fire. Combustion is a chemical reaction in which a combustible material and an oxidizing agent (typically the oxygen in the air) produce heat or energy and other products that promote a self-sustaining process. To continue the process, heat must generate more rapidly than it dissipates. If the process continues to grow at a rapid rate and is unmanaged, the prevailing conditions could result in an explosion. Fire is a chemical reaction that produces energy in the form of heat, light, and flame that is rapid and self-sustaining. It requires a combustible fuel, a source of heat (energy), and oxygen (oxidizer).

It may appear that fire and combustion describe the same self-sustaining chemical process, but there is a difference. In the combustion process, the released energy stays in the reaction to continue the reaction. Fire is a form of combustion that emits and dissipates energy as heat and light. This basic distinction establishes a platform for exploring the fundamental concepts of fire behavior.

The Fire Triangle

For many years, the **fire triangle** has served as a teaching tool to geometrically depict the relationship between fuel, air (oxygen), and heat (energy). Each is necessary for combustion, as illustrated by the triangle in which each side represents one component **FIGURE 1-1**. For fire to exist, all three must be present in sufficient quantities. When the three elements are combined in sufficient quantities, the heat source, oxygen, and fuel chemically react to cause a discernible release of energy at a rate that correlates to the quantity of fuel available to sustain the fire. The reduction or elimination of any one of the three elements will result in extinguishment of the fire. In addition, changing the proportions of the three elements determines whether the fire will smolder, burn slowly, or burn rapidly.

The fire triangle demonstrates that extinguishing a fire is possible by several different methods. For example, applying sufficient amounts of water to fire will reduce heat, shutting down a gas line to a stove will remove fuel, or flooding an area with carbon dioxide gas will reduce the amount of oxygen available to sustain a fire. For many years, the fire triangle provided a simplified and understandable model of the fire process. However, continued research led to a more sophisticated and accurate model of the fire process called the *fire tetrahedron*.

TIP

Segregating the three components of fire represented by the fire triangle is also the basic method referenced by fire prevention codes to prevent fires from occurring.

The Fire Tetrahedron

Fire research in the latter part of the twentieth century led to a better understanding of the combustion process. Scientists and researchers realized that certain extinguishing agents were effective against fires, but in a manner that seemed to defy the rules. All three legs of the fire triangle remained, yet the fire went out. There was no appreciable cooling effect, there was sufficient fuel present, and there was still adequate oxygen to support combustion. The question repeatedly asked was, "Why did the fire go out?" The conclusion reached by scientists and researchers was that the application of certain extinguishing agents interrupted the chemical chain reaction and interfered with its ability to self-sustain.

This ongoing research led to the development of an improved four-sided geometric depiction of how fire is sustained. Refined from the fire triangle, the **fire tetrahedron** illustrates how a fourth element—the chain reaction—must also be present for ongoing fire **FIGURE 1-2**. Elimination of any one of the four elements will result in extinguishment. While the fire triangle depicts the three elements needed to start a fire, the fire tetrahedron depicts fire's nature as an uninhibited, chemical, or self-sustaining chain reaction once ignition occurs.

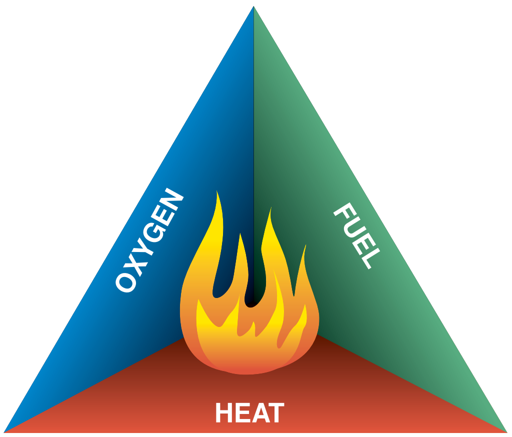


FIGURE 1-1 The components of the fire triangle: fuel, oxygen, and heat.

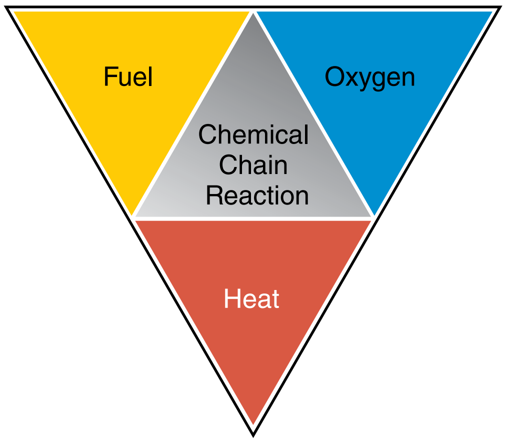


FIGURE 1-2 The fire tetrahedron includes the chemical chain reaction as an essential part of the combustion process.

Fire and Flame Types

There are four discernible types of fire: diffusion flame, smoldering, spontaneous combustion or self-heating, and premixed flame. Although all require fuel, a source of heat, and oxygen, each type of fire has unique characteristics.

Diffusion Flame

The most recognizable type of fire, **diffusion flame**, is the flame seen when lighting a match; this is also the flame seen from a candle, campfire, forest fire, or structure on fire. As evident from these examples, most natural flaming fires are diffusion flame fires. This type of fire requires the presence of a combustible gas because the visible flame is a gaseous reaction. When a flame is visible, it is usually the result of a combustible gas emitted by the burning material and mixed with the oxygen in the air surrounding the material. In the diffusion flame process, the gas fuel and oxygen move into the reaction zone of the flame from opposite sides. Once consumed, the fuel and oxygen combustion products spread out or "diffuse" from the flame.

Smoldering

Another type of fire is the smoldering fire. **Smoldering** is evident in the glow of the charcoal in a backyard grill or cigarette paper and tobacco burning in an ashtray. There is no flame with a smoldering fire, but there is still significant heat. With this type of fire, the air flows over the surface area of the burning material, providing enough oxygen to sustain the slow combustion process. Sometimes smoldering is the beginning phase of what could become a flaming fire. For example, many house fires occur when a carelessly discarded cigarette or match encounters furniture. When the source of heat contacts the material, there may be enough heat and oxygen to sustain combustion but not enough to produce a flame. Essentially, the material of a smoldering fire glows, and when the appropriate amount of oxygen is available and there is sufficient heat generated, the material will erupt into a flame. Glowing, smoldering material may also be present in the final phase of an earlier fire event, when the fuel may have exhausted its ability to produce any more combustible gases or the composition of the burning material is unable to produce any combustible gases.

Spontaneous Combustion/ Self-Heating

There are times when a fire will start without a known external heat source applied to the material. This type of fire is known as **spontaneous combustion**. Spontaneous combustion results when certain materials undergo oxidation in an environment that limits heat dissipation. Under this circumstance, the oxidation process creates heat that is not adequately released into the air, resulting in the heat remaining in the area of the reaction. Because the heat remains in the area of the reaction, the temperature increases and further promotes the reaction. Once there is a sufficient amount of heat produced, it is possible for the material to flame or smolder. The amount of time necessary for this process to take place depends on the material and environment involved. Some materials, such as cotton rags soaked with linseed oil, may ignite within a few hours. Other materials, such as freshly cut hay, may take weeks to ignite. Not all materials self-heat, but some with a high tendency could lead to spontaneous combustion.

TIP

The term *spontaneous combustion* describes a general chemical process, but there are other terms, including *spontaneous heating* and *self-heating*, that are used interchangeably to describe the process. Spontaneous combustion is commonly associated with the improper storage of materials, inadequate ventilation at the storage site, exposure of the stored materials to moisture, and contact between stored materials and other fibrous combustible materials.

Premixed Flame

A **premixed flame** fire is more familiar than most might expect. It is used to help people get ready for the day ahead or to transport them to a destination. When heating water or air with a gas fuel, cooking meals, or driving to work in a gasoline-powered vehicle, a premixed flame fire is involved. This type of fire requires gas fuel and air to mix before ignition or combustion occurs. For any gas fuel to ignite there must be an appropriate mix of the gas fuel and air. Specifically, the gas fuel must be within its flammable limits, which describe the lower and upper percentages of gas concentration in the air where the mixture will ignite. For example, acetylene has a flammable limit range between 2.5 and 100 percent, meaning that any concentration of acetylene in air at 2.5 percent or above will ignite. Changes in atmospheric temperature and pressure can increase or decrease the flammable limit range of any material. Therefore, knowing the flammable limits of any gas fuel that is part of a premixed fire flame plays a key role in safely managing the incident, especially when survivability is at stake.

The Stages of Fire

Fires develop and evolve through a specific series of phases or stages identified as the incipient, growth, fully developed, and smoldering/decay stages. Fire suppression methods must be appropriate for the conditions that exist during each stage.

Incipient Stage

To start a fire, three things are necessary: a heat source, fuel, and enough oxygen to support combustion. In most instances, the heat source is external, such as from a small flame or spark. However, a source of heat can start internally by spontaneous combustion or spontaneous heating to the point of ignition. No matter the source, the **incipient stage** occurs when the heat source, fuel, and oxygen come together to generate more heat than is dissipated to promote the uninhibited chain reaction **FIGURE 1-3**. At that point, there is no need for any additional sources of heat because the process will generate the necessary heat to self-sustain if sufficient fuel and oxygen are present. With sufficient fuel and oxygen, the fire will intensify and transition to the growth stage.

Growth Stage

Once there is ignition, the fire will survive by consuming the air and materials necessary to generate the flammable gas and sustain the combustion process. How fast and large a fire grows depends on several factors, including the oxygen supply, the amount and type of fuel, the container or compartment size, and the quality of compartment insulation.

In the **growth stage** (also called the free burning stage), adequate oxygen must be available, or fire growth will subside and extinguishment will result. The oxygen may be present in gaseous form or in the form of a chemical oxidizer. The amount of available oxygen directly affects the speed at which fire growth occurs. Fires that occur in oxygen-enriched atmospheres or that involve chemical oxidizers often develop rapidly **FIGURE 1-4**.

Additional growth factors include the amount, type, and form of the fuel. For example, a fire involving 100 lb of hardwood has the potential to release about 860,000 **British thermal units (Btu)** of energy in the form of heat. (Note: The generally accepted heat value for hardwood at zero moisture is 8600 Btu/lb; therefore, 8600 Btu/lb $\times$ 100 lb $=$ 860,000 Btu.) Fire growth would be slow developing if the wood pieces were tightly stacked in rows and on top of each other because oxygen would not easily reach the pieces deeper in the stack. However, fire growth would be rapid and intense if the wood pieces were stacked in cribs that exposed the wood to enhanced air circulation. That same 100 lb of wood in the form of sawdust suspended in air could burn with explosive speed and force. In all three cases, the same amount of fuel, if fully consumed, releases the same total amount of heat energy; the difference is how fast that amount of energy is released.

The size of a structure, as well as the shape of surrounding walls, ceilings, and roofs, also has a significant impact on fire growth. Large compartments allow heat to dissipate. Low ceilings hold in heat and reflect radiant heat energy back down to the space, further preheating available fuel. Insulation or the ability of the

FIGURE 1-3 The incipient stage of a fire.

Courtesy of NIST.

FIGURE 1-4 The growth stage of a fire.

Courtesy of NIST.

container or compartment to retain heat and prevent dissipation further accelerates preheating of the available fuel. Returning to the example of spontaneous combustion involving linseed oil–soaked rags, the storage or disposal of the rags in close proximity to each other can create conditions in which the rags themselves act as insulation and hold enough heat to reach their ignition temperature. However, if the heat dissipates prior to ignition, the rags merely dry and stiffen.

If the fire continues to grow and is able to contain the energy, preheat the fuel, and increase the temperature, flashover could occur. **Flashover** is a term describing the transition between the growth and fully developed stages in which the temperature in a room or space reaches a point at which all of the surfaces of the room or space simultaneously ignite, immediately leading to full room involvement. With the use of more plastics and synthetic materials in the built environment, flashover can occur more rapidly than with natural materials. However, not all fires reach flashover or the fully developed stage owing to rapid fire department intervention, lack of oxygen, or lack of fuel. No matter when or where flashover occurs, chances of survival in the area of flashover is pretty much zero, and at that point, the fire has reached the fully developed stage.

Fully Developed Stage

The **fully developed stage** is the instant the fire is consuming all available fuel and releasing the most amount of heat produced from the available oxygen and fuel in the compartment **FIGURE 1-5**. At this point in the fire's development, the heat level is extremely high and starts to break down the available fuel producing gases and smoke. The amount of heat released from the compartment is dependent on the size of the compartment and the ventilation openings. If the ventilation is limited, more unburned gases are produced and the pressure from the gas and smoke will build in the compartment. Once the heat release is high enough and gases escape, they will migrate, mix with the available oxygen, and transfer enough heat to start fires in the areas adjacent to the area of fire origin. This process will continue as long as there is fuel or oxygen. However, at some point, the fuel will be consumed, or the oxygen depleted, which leads to the smoldering/decay stage.

Smoldering/Decay Stage

When a fire begins to subside to the point at which the available fuel is exhausted or the oxygen level drops below 16 percent, it has reached the **smoldering/decay stage** **FIGURE 1-6**. Burning that continues after that point will be in the form of glowing combustion, or smoldering, and will continue until all the fuel is completely exhausted or the temperature within the compartment drops below the ignition temperature of the fuel. Even though there is no visible flame, carbon monoxide, other toxic gases, and hazardous chemicals and materials will most likely be present; therefore, caution must be taken. Depending on the available fuel, the introduction of additional air may stimulate enough burning to regenerate a flaming fire.

Forms of Heat Transfer

Heat transfers from one object to another in three ways: conduction, convection, and radiation. All three mechanisms of heat transfer are used every day to cook, heat homes, and protect automobiles from overheating, but sometimes hostile fires develop from one of these methods. An understanding of the

FIGURE 1-5 The fully developed stage of a fire.
Courtesy of NIST.

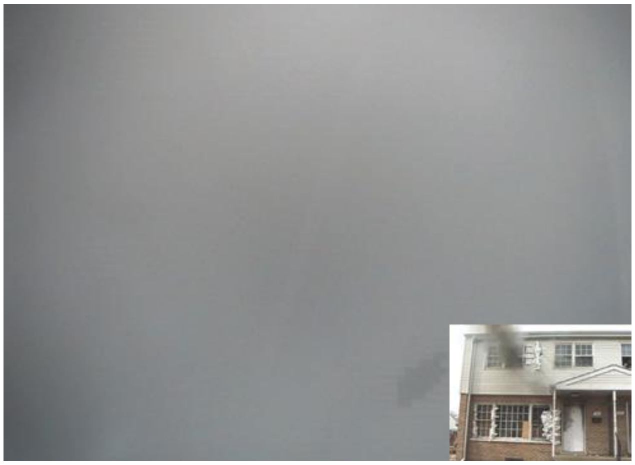


FIGURE 1-6 The smoldering/decay stage of a fire.
Courtesy of NIST.

mechanisms of heat transfer is important to reducing fire spread and extinguishing fires.

Conduction

To conduct means to transmit or convey. **Conduction** is the transfer of heat from one body of material to another by direct contact **FIGURE 1-7**. When objects are exposed to heat, the movement of molecules within them increases, causing the temperature of the objects to increase as heat energy naturally attempts to move to lower temperature areas or objects. Some materials conduct heat better than others. Heavy, dense materials are generally the best for heat conduction because they absorb and transmit heat rapidly and evenly. Metals such as copper and aluminum are good conductors of heat and thus are effective as a material for cookware. Glass cookware, although easier to clean and maintain, is not as good for cooking because glass is less dense and thus does not conduct heat as well. Other less dense or porous materials like fiberglass, wood, and air are generally poor conductors. The rate of heat transfer is dependent on the efficiency of the material as a conductor.

Convection

Convection is the transfer of heat from one body to another through a medium such as a liquid or gas **FIGURE 1-8**. Automobile radiators use coolant to transfer heat from the engine to the radiator, where it dissipates by convection. In building fires, heat can transfer through the air in convection currents. The size and shape of the fire compartment directly influence the effect of convection. Although it is known that convection is a major factor in fires that occur inside structures, it is also a significant factor in major conflagrations. Reports of hurricane-force winds generated from the updraft of convection currents are common.

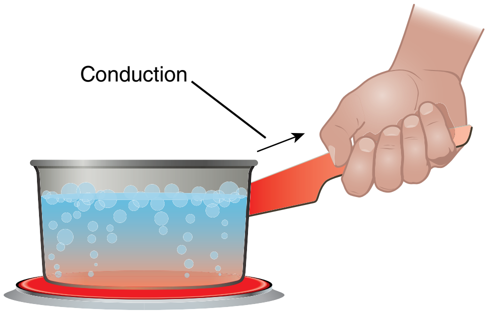


FIGURE 1-7 Conduction.

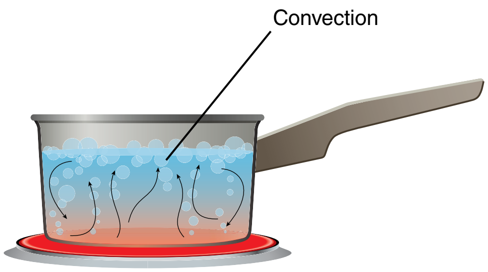


FIGURE 1-8 Convection.

Radiation

Radiation is the transfer of heat through electromagnetic energy, such as light **FIGURE 1-9**. The most profound example of radiation is the sun that heats the earth through millions of miles of space. Radiant heat travels in a straight line. Within structure fires, it has a significant impact on the speed at which flashover occurs. During conflagrations, radiation is a significant cause of fire spread from building to building and from block to block.

Methods of Extinguishing Fires

The basic methods used to extinguish a fire are cooling, oxygen reduction, removing the fuel supply, and interrupting the chain reaction **FIGURE 1-10**. These basic methods are the basis for the design of fire extinguishing systems.

Cooling

The design of water-based fire extinguishing systems is based on the premise that 1 gallon of water, properly applied, can absorb about 8000 Btu. Fittingly, this is the same amount of heat that 1 lb of common combustible material releases during combustion. However, with the use of composite materials, plastics, and increased fuel loads in the home and workplace, the Btu output developed by an ordinary room-and-contents fire can more than double. Many plastics produce twice the amount of heat per pound as common combustibles.

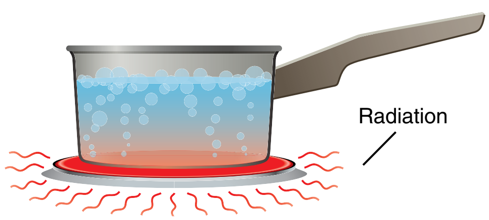
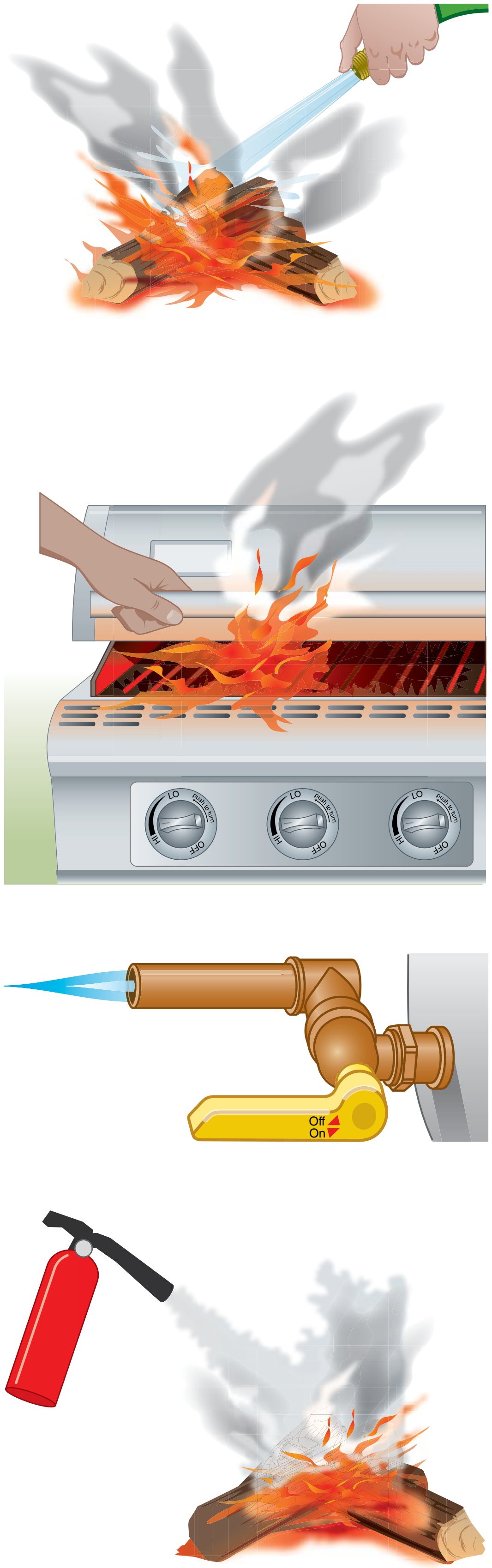


FIGURE 1-9 Radiation.



(A)

(B)

(C)

(D)

FIGURE 1-10 The four basic methods of fire extinguishment. **A.** Cool the burning material. **B.** Exclude oxygen from the fire. **C.** Remove fuel from the fire. **D.** Interrupt the chemical reaction with a flame inhibitor.

This means that it could take twice the amount of water to extinguish a fire involving these materials than it would a fire involving the same total weight of ordinary combustible material. Therefore, the required amount of water properly applied is essential to extinguish a fire. Water application must be at a sufficient rate and quantity to reach the seat of the fire, or the fire might flare up. The types of fuel, the form of the material, and the storage arrangement also have a significant impact on the effectiveness of water-based systems in cooling the fire.

Oxygen Reduction

To starve a fire, control of the air intake in the area of the fire helps to reduce or remove the oxygen supply. Foam is a commonly used suppression agent because it can cover leaking liquid fuel so that oxygen cannot reach the fuel. On many ships, cargo holds have sealed hatches to prevent oxygen from getting into the hold. Below-grade utility vaults may lack airtight hatches or doors, but the introduction of heavier-than-air carbon dioxide (CO_2) displaces the atmospheric oxygen to accomplish the same goal. Both the application of foam and the introduction of carbon dioxide are common oxygen reduction techniques.

Removing or Interrupting the Fuel Supply

In some circumstances, fire fighters may set intentional, controlled fires known as backfires to remove the fuel ahead of a hostile, uncontrolled fire. Backfires are sometimes set ahead of wildland fires in an effort to interrupt the fuel supply of combustible material. In other cases, the use of foams that blanket flammable and combustible liquids works to prevent the liberation of vapors and provides cooling to spills and leaks. Additionally, water flow from an automatic sprinkler head will not only attack a fire by cooling, it will also pre-wet any adjacent fuels, making it difficult for the fuel to ignite and thus assisting with the removal of the fuel supply.

Interrupting the Chain Reaction

Dry chemical, halon, and other clean agent suppression products break the chain reaction needed to sustain fire through a chemical reaction with the products of combustion. Depending on the suppression agent, breaking the chain reaction is accomplished by displacing the available oxygen, chemically decomposing and isolating the material from the other available elements, or changing the environment so that more energy is required to heat the environment and sustain combustion.

Classes of Fire

In the early 1900s, **UL** (formerly known as Underwriters Laboratories) developed a method of classifying or categorizing fires based on the extinguishing agent that was appropriate for the type of fire. The classification system recognized that fires involve different materials, which necessitate the use of specific extinguishing agents and techniques. The application of the wrong agent may not only prove ineffective, it could compound the hazard. The fire classification system is a quick, no-frills method of matching extinguishing agents to fire hazards by using letters from the alphabet to designate the classification. The system is still in use today, and labels bearing the classifications are affixed to portable fire extinguishers, tanks, and vessels containing extinguishing agents and appear on packaging and in literature regarding fire hazards, including **Safety Data Sheets (SDS)**.

Class A Fires and Extinguishing Agents

A **Class A fire** involves ordinary combustibles such as cloth, grain, paper, some plastics, rubber, and wood **FIGURE 1-11**. Class A materials such as wood or similar products release between 7000 and 8000 Btu per pound. Water is the most effective suppression agent for Class A fires because it has the ability to absorb the heat and reduce the temperature below the material's ignition temperature. Although some dry chemical agents and some halon gas mixtures hold listings for use on Class A fires, water or Class A foam may be the better choice.

TIP

Although considered a Class A ordinary combustible, rubber tires can produce between 12,000 and 16,000 Btu per pound that in some instances, makes the use of water or foam ineffective.

Class B Fires and Extinguishing Agents

A **Class B fire** involves flammable and combustible liquids and gases **FIGURE 1-12**. Class B agents typically extinguish fires through a smothering or blanketing action or by a combination of smothering and cooling to keep oxygen away from the flammable vapors in order to interrupt the chemical chain reaction. There are many approved types of foam as well as carbon dioxide and other gaseous agents, dry chemical agents, and halons used on Class B fires.

Class C Fires and Extinguishing Agents

A **Class C fire** involves energized electrical equipment in which the choice of extinguishing agents must be appropriate to minimize potential danger to those involved in fighting the fire **FIGURE 1-13**. Because electricity is the source of heat and energy, shutting off the electricity is critical to stopping the process. However, the electricity may have involved other classes of materials in the area of the fire; as such, even if the electricity is shut off, the fire may require additional suppression activities. Once the electricity is off, the fire changes from the Class C electrical fire designation to another classification of fire. Only fires involving energized electrical equipment such as electric

FIGURE 1-11 A Class A fire involves wood, paper, or other ordinary combustibles.

FIGURE 1-12 A Class B fire involves flammable liquids such as gasoline.

FIGURE 1-13 A Class C fire involves energized electrical equipment.

panels, transformers, and home appliances are Class C fires. When a truck loaded with televisions is in an accident and catches fire on the way to an appliance store, it is not a Class C fire but rather a Class A fire. If the truck's fuel tanks rupture and leaking fuel ignites, the resulting liquid fuel fire is classified as Class B.

TIP

When encountering a Class C fire, electricity is the source of heat and energy; therefore, shutting off the electricity is critical to stopping the process. When the electrical equipment is de-energized, the fire reclassifies as another type of fire depending on what material or fuel is involved.

Class D Fires and Extinguishing Agents

A **Class D fire** involves combustible metals such as aluminum, calcium, lithium, magnesium, potassium, sodium, titanium, and zirconium **FIGURE 1-14**. During some manufacturing processes, significant quantities of metal dust and fine particles develop. If airborne, these metals can be dangerous and potentially explosive. Fires involving metals require the use of extinguishing agents that are appropriate to the type of metal and will not react with the burning material. Many Class D extinguishing agents are termed *dry powder* and are inert materials that smother the fire, reducing the oxygen concentration around the fire to a level below what is necessary to sustain combustion. The use of other classes of extinguishing agents, including water, on Class D materials can be extremely hazardous.

FIGURE 1-14 A Class D fire involves metals such as aluminum, calcium, lithium, magnesium, potassium, sodium, titanium, and zirconium.

TIP

Many automobile manufacturers use magnesium components to reduce the weight and increase the strength of the vehicle. Care should be taken when dealing with combustible metals because special agents are needed to prevent problems associated with the application of water.

Class K Fires and Extinguishing Agents

A **Class K fire** involves cooking appliances using combustible vegetable or animal oils and fats **FIGURE 1-15**. In 1994, UL adopted a new standard titled UL 300, *Fire Testing of Fire Extinguishing Systems for Protection of Restaurant Cooking Areas*. The new standard was developed in response to a series of large-loss fires involving commercial cooking operations in which existing fixed fire suppression systems operated but failed to suppress the fire. The investigation and research that followed revealed that cooking establishments were updating their equipment and installing modern high-efficiency insulated fryers that contained significantly larger amounts of cooking oil compared with the amounts used years before. In addition, to satisfy a health-conscious public, restaurant owners were replacing animal fats and oils with vegetable oils, which heat to higher temperatures than animal products.

FIGURE 1-15 A Class K fire involves combustible cooking oils and fats.

The combination of a greater amount and hotter oil resulted in fires in which dry chemical agents did not effectively cool or suppress the fire. With the adoption of UL 300 and UL 711, *Standard for the Rating and Testing of Fire Extinguishers*, a new class of fire was established.

Class K extinguishing agents are wet-chemical agents that extinguish fires through a process called **saponification**. Through saponification, the fatty acids in the cooking medium react with the extinguishing agent and convert to foam. This soapy foam blankets the surface of the burning liquid, extinguishing the fire. Liquid in the extinguishing agent cools the cooking medium sufficiently to help maintain the foam blanket until the cooking medium cools below its **autoignition temperature**.

In addition to fixed fire suppression systems, the model codes and standards require supplemental hand-held fire extinguishers for the protection of commercial cooking equipment. Class K first appeared in the 1998 edition of the National Fire Protection Association (NFPA®) standard NFPA 10, *Standard for Portable Fire Extinguishers*.

TIP

The United States and Canada follow the same fire classification system, but different classification systems exist in other parts of the world. For example, in Europe and Australia, fire classification is as follows:

- Class A—Ordinary Combustibles
- Class B—Flammable Liquids
- Class C—Flammable Gases
- Class D—Combustible Metals
- Class E—Live Electrical Equipment
- Class F—Oil and Fats

This classification system adds a specific classification category for flammable gas and uses different classification names for live electrical equipment fire (Class E) and vegetable oil/animal fat fire (Class F). Both systems are very practical, as the fundamental purpose of classification is to facilitate the application of the appropriate suppression agent to the type of fire encountered.

Wrap-Up

CHAPTER SUMMARY

- The *fire triangle* and *fire tetrahedron* describe the relationship between the components required to sustain combustion. These models provide a simple illustration of what elements are necessary for fires to occur and show the logic behind the methods used to extinguish fires.
- The four different types of fire are diffusion flame, smoldering, spontaneous combustion, and premixed flame.
- The type of ignition, the amount of available fuel, the form of fuel, and the amount of available oxygen all play significant roles in fire development.
- The four stages of fire are incipient, growth, fully developed, and smoldering/decay.
- The three methods of heat transfer are conduction, convection, and radiation.
- There are four basic methods used to extinguish fires: cooling, oxygen reduction, removing the fuel supply, and interrupting the chain reaction. These are the same basic methods used in the design of fire protection systems.
- A fire classification system helps to determine the types of extinguishing agents to use, thus reducing the possibility of applying an inappropriate extinguishing agent to a fire.

KEY TERMS

Autoignition temperature The lowest temperature at which a combustible material ignites in air without a spark or flame (National Fire Protection Association 2017, *NFPA 921,* Section 3.3.16).

British thermal unit (Btu) The quantity of heat required to raise the temperature of 1 lb of water 1°F at the pressure of 1 atmosphere and temperature of 60°F; a British thermal unit is equal to 1055 joules, 1.055 kilojoules, and 252.15 calories (National Fire Protection Association 2017, *NFPA 921,* Section 3.3.22).

Class A fire Fires in ordinary combustible materials, such as wood, cloth, paper, rubber, and many plastics (National Fire Protection Association 2018, *NFPA 1,* Section 3.3.117.1).

Class B fire Fires in flammable liquids, combustible liquids, petroleum greases, tars, oils, oil-based paints, solvents, lacquers, alcohols, and flammable gases (National Fire Protection Association 2018, *NFPA 1,* Section 3.3.117.2).

Class C fire Fires that involve energized electrical equipment (National Fire Protection Association 2018, *NFPA 1,* Section 3.3.117.3).

Class D fire Fires in combustible metals, such as magnesium, titanium, zirconium, sodium, lithium, and potassium (National Fire Protection Association 2018, *NFPA 1,* Section 3.3.117.4).

Class K fire Fires in cooking appliances that involve combustible cooking media (vegetable or animal oils and fats) (National Fire Protection Association 2018, *NFPA 1,* Section 3.3.117.5).

Combustion A chemical process of oxidation that occurs at a rate fast enough to produce heat and usually light in the form of either a glow or flame (National Fire Protection Association 2017, *NFPA 921,* Section 3.3.35).

Conduction Heat transfer to another body or within a body by direct contact (National Fire Protection Association 2017, *NFPA 921,* Section 3.3.38).

Convection Heat transfer by circulation within a medium such as a gas or a liquid (National Fire Protection Association 2017, *NFPA 921,* Section 3.3.39).

Diffusion flame A flame in which fuel and air mix or diffuse together at the region of combustion (National Fire Protection Association 2017, *NFPA 921,* Section 3.3.48).

Fire A rapid oxidation process, which is a chemical reaction resulting in the evolution of light and heat in varying intensities (National Fire Protection Association 2017, *NFPA 921,* Section 3.3.66).

Fire hazard Any situation, process, material, or condition that, on the basis of applicable data, can cause a fire or explosion or that can provide a ready fuel supply to augment the spread or intensity of a fire or explosion, all of which pose a threat to life or property (National Fire Protection Association 2018, *NFPA 1,* Section 3.3.124).

Fire protection system Any fire alarm device or system or fire-extinguishing device or system, or combination thereof, that is designed and installed for detecting, controlling, or extinguishing a fire or otherwise alerting occupants, or the fire department, or both, that a fire has occurred (National Fire Protection Association 2018, *NFPA 1,* Section 3.3.267.11).

Fire tetrahedron The geometric depiction of the relationship between fuel, heat, oxygen, and the uninhibited, chemical, or self-sustaining chain reaction necessary to sustain combustion; each element is represented by one side of the tetrahedron.

Fire triangle The geometric depiction of the relationship between the fuel, oxygen, and heat necessary for combustion; each element is represented by one side of the triangle.

Flammable limits The range in which the concentration of a fuel and air are in the proper mix to propagate combustion when ignited; the limits for a material are defined by the upper flammable limits (UFL) and the lower flammable limits (LFL).

Flashover A transition phase in the development of a compartment fire in which surfaces exposed to thermal radiation reach ignition temperature more or less simultaneously and fire spreads rapidly throughout the space, resulting in full room involvement or total involvement of the compartment or enclosed space (National Fire Protection Association 2017, *NFPA 921,* Section 3.3.89).

Fuel load The total quantity of combustible contents of a building, space, or fire area (National Fire Protection Association 2017, *NFPA 921,* Section 3.3.93).

Fully developed stage The stage reached when the fire is consuming all available fuel and releasing the most amount of heat from the available oxygen and fuel in the compartment or structure.

Growth stage The stage of a fire (also called the free burning stage) at which the energy level begins to grow by consuming the air and materials necessary to generate a flammable gas and sustain combustion.

Heat transfer The exchange of thermal energy between materials through conduction, convection, and/or radiation (National Fire Protection Association 2017, *NFPA 921,* Section 3.3.106).

Ignition The process of initiating self-sustained combustion (National Fire Protection Association 2017, *NFPA 921,* Section 3.3.112).

Incipient stage The stage of a fire at which the heat source, fuel, and oxygen come together to generate more heat than is dissipated to promote an uninhibited chain reaction.

Oxidation The process of combining a substance or material with oxygen.

Premixed flame A flame for which the fuel and oxidizer are mixed prior to combustion, as in a laboratory Bunsen burner or a gas cooking range; propagation of the flame is governed by the interaction between flow rate, transport processes, and chemical reaction (National Fire Protection Association 2017, *NFPA 921,* Section 3.3.144).

Preplan An evaluation of a facility or location from which the emergency responders develop a plan of action to deal with the potential hazards and emergencies.

Radiation Heat transfer by way of electromagnetic energy (National Fire Protection Association 2017, *NFPA 921,* Section 3.3.153).

Safety Data Sheet (SDS) The document that describes composition of a material, hazardous properties and hazard mitigation, and disposal information (National Fire Protection Association 2019, Section 3.3.77).

Saponification The process in which the fatty acids in a cooking medium react with the extinguishing agent and convert to foam.

Smoldering Combustion without flame, usually with incandescence and smoke (National Fire Protection Association 2017, *NFPA 921,* Section 3.3.172).

Smoldering/decay stage The point at which the available fuel of a fire is exhausted or the oxygen level has dropped below 16 percent.

Spontaneous combustion The process in which a material starts to break down chemically, resulting in heat that cannot dissipate, continued heating of the material, and eventually fire.

UL An independent organization (previously known as Underwriters Laboratories) that is recognized throughout the world as a leader in fire and safety testing and evaluation to determine if products meet certain established safety and performance standards.

CASE STUDY

While conducting a preplan of a sheet metal shop, you document the building's layout and various use areas, materials used, storage arrangements, exits, and fire protection features. The shop has a business office and areas for cutting and welding, metal fabrication, painting, and shipping. The only fire protection system in the building is a dry chemical system for the paint booth. During your walkthrough, you observe an oxyacetylene torch, metal shavings around the fabrication equipment, flammable and combustible liquids, plastic pallets, and paper products used for shipping.

1. Based on the information provided, what type of fire is most unlikely to start at this facility?

- **A.** Diffusion flame
- **B.** Smoldering
- **C.** Spontaneous combustion
- **D.** Premixed flame

2. Which classification of fire is most unlikely to occur at this facility?

- **A.** Class D
- **B.** Class K
- **C.** Class B
- **D.** Class C

3. Which method would best extinguish a fire that started in the metal fabrication area of the facility?

- **A.** Removing or interrupting the fuel supply
- **B.** Interrupting the chain reaction
- **C.** Cooling
- **D.** Oxygen reduction

4. If a fire were to start at this facility, which mechanisms of heat transfer are most likely to spread the fire?

- **A.** Conduction and convection
- **B.** Conduction and radiation
- **C.** Convection and radiation
- **D.** Conduction, convection, and radiation

CHALLENGING QUESTIONS

1. Define the terms *fire* and *combustion* and explain the difference between them.
2. Explain the term *oxidation*.
3. Compare and contrast the fire triangle and the fire tetrahedron.
4. Using the fire tetrahedron, describe four methods of fire extinguishment.
5. Differentiate the classifications of fire and give a practical example of each.
6. List the types of fire and explain each.
7. List the stages of fire development and explain each.
8. What are the factors that contribute to flashover?
9. Fuel dispensers at service stations are equipped with signs that include instructions and safety warnings. Use the fire tetrahedron to explain the reasons for these warnings.
10. Each year, wildland fires destroy thousands of homes. Using the modes of heat transfer for guidance, develop a list of strategies to reduce the amount of damage.

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CHAPTER 2

Establishing the Relationship Between Fire Behavior, the Model Codes, and Fire Protection Systems

Fire Protection Systems and the Model Code Process

LEARNING OBJECTIVES

At the conclusion of this chapter, you will be able to:

- Describe the advantages to governments and organizations that adopt model codes.
- Define the terms *code* and *model code*.
- Name the two most prominent model code organizations.
- Describe the International Code Council® (ICC) model code development process.
- Describe the National Fire Protection Association (NFPA®) model code development process.
- Define the terms *referenced standard* and *code amendment*.
- List the two most important code-related conditions that determine the installation requirements for fire protection systems.

Case Study

The model code development cycle takes approximately 3 years from the start to the publishing of the new model codes. During the code development process, new codes are proposed, some are modified, and others deleted. Changes to the codes can be proposed for a number of reasons, but generally, the changes are to make improvements to existing requirements; deal with new processes, materials, equipment, or methods of construction; and improve life safety. In the majority of state and local jurisdictions, new codes are not retroactive if the use and occupancy of the facility have not changed. However, for a number of events there was a significant loss of life and injury that required a reevaluation of the conditions causing the event, the applicable codes, the level of enforcement, and whether the applicable codes should be changed.

One such event took place on February 20, 2003, when a fire erupted during a concert at an assembly occupancy (nightclub) in West Warwick, Rhode Island. The fire started within seconds after the discharge of pyrotechnic devices that emitted sparks and came into contact with polyurethane foam that was lining the walls around the stage. Within 25 seconds of ignition, flames had reached the ceiling. At approximately 41 seconds, the fire alarm sounded, and within 1 minute, smoke had covered the entire ceiling of the main room. One minute and 15 seconds after ignition, the smoke had reached the front doors. As many of the occupants tried to exit through the front door, the exit became clogged and nearly unusable. Before 2 minutes had passed, black smoke had reached the front door, and now the occupants were piled on top of each other, unable to move. Conditions rapidly deteriorated, and at approximately 3½ minutes, black smoke was pouring out of all the front windows and the front door. Four minutes after ignition, black smoke was venting out of all openings. Five and a half minutes after ignition, flames had reached the front windows and door area. This unfortunate event resulted in 100 deaths and 200 injuries.

Within weeks of the tragedy, the Rhode Island General Assembly convened a commission to study changing the laws related to the existing fire codes. In June 2003, the commission submitted more than 30 recommendations to the governor of Rhode Island for review and consideration. Included in the recommendations were elimination of the "grandfather clause" that permitted establishments to only meet the fire code in force at the time of construction or major renovation; adoption of model codes; installation of fire extinguishers, fire alarms, and fire sprinkler systems when certain thresholds are met or conditions exist; installation of exit signs; crowd control measures; interior finish requirements; and regulations on the use of pyrotechnics. The Commonwealth of Massachusetts also convened a task force to review public safety in assembly occupancies. This was mainly because a third of the victims in the fire were Massachusetts residents. Many of the recommendations were similar to Rhode Island's, but others were more restrictive.

It is not uncommon for codes to remain in force as originally adopted. Strong opposition to making any changes to codes can be due to financial or other hardships, but many times, an event demands a new look at the conditions that resulted in a tragedy. The Rhode Island event clearly illustrates how quickly a tragedy can unfold and force change and improvements to life safety.

1. What is the process by which codes are developed and adopted in your jurisdiction?
2. Does your jurisdiction have any authority to make retroactive code changes or does the power lie with a higher authority of government?
3. Why is there still opposition from the public and private sectors to implement retroactive code changes that could save lives and property?

Sources: Duvall, Robert F. *NFPA Case Study: Nightclub Fires.* Quincy, MA: National Fire Protection Association, 2006;

Grosshandler, William, Nelson Bryner, Daniel Madrzykowski. *NIST NCSTAR2: Vol. 1, Report of the Technical Investigation of the Station Nightclub Fire.* Gaithersburg, MD: United States Department of Commerce, National Institute of Standards and Technology, June 30, 2005.

Introduction

Building and fire codes provide uniform and consistent guidelines for all parties involved in the construction of buildings and management of the occupancy conditions throughout the life of a building. Developers, design professionals, contractors, and building, health, and fire officials deal with codes every day. The purpose is to ensure the well-being of building occupants by preventing collapse, fires, and unhealthy conditions. While many use codes every day, some do not know or understand the process by which these codes evolve, the organizations that create them, or the process of writing, developing, and adopting codes. In order to understand the origin and significance of building, fire, health, and life safety codes, it is important to know how the code development process works. This chapter explores the code development process and the model code requirements related to installation of fire protection systems.

Code and Standards Development for Government

For most governments, the task of writing and publishing codes, standards, and recommended practices is daunting. The process involves a great amount of time, effort, and personnel to keep up with the latest design innovations, materials, methods, and processes that emerge every day. It could take years to write a new code or standard and years to adopt the code. Instead of writing large volumes of codes, standards, and recommended practices that cover all aspects of building design and construction, most federal, state, and local governmental agencies adopt model codes written by private, not-for-profit organizations. The model code organizations devote significant time and effort to the code and standard development process. As such, it is cost-effective and practicable for a government to adopt model codes that have gone through an extensive review process involving the input and recommendations of many technical experts and interested parties. In addition, adopting already-published model codes means they are coordinated and compatible. A coordinated code development process eliminates discrepancies or contradictions when applying or enforcing the codes.

A Model Code

In order to understand the model code process, it is necessary to understand the terms **code** and **model code**. A code is a system of rules, regulations, or laws usually put into effect by local, state, or federal governments that has statutory authority to be enforced. Simply put, a code states what a person can or cannot do. A model code is a system of rules, guidelines, methods, and regulations typically developed by private, not-for-profit organizations. These organizations provide a forum for interested parties, technical committees, government, and the general public to come together to propose, debate, modify, reject, or approve rules, regulations, and processes by consensus. Once approved, the rules, regulations, and processes form a code that is available for local, state, and federal governments and agencies to **adopt** at no cost. Here, the term “model” implies that the code is a guideline, standard, or rule written by a nongovernmental organization. By adopting model codes into law, the local, state, or federal government agency implements the code for all to follow.

Model Code Organizations

The genesis of the model codes actually started with the stock fire insurance industry in the mid-1800s. Rocked by large losses after the Civil War and an 1866 $10 million conflagration in Portland, Maine, the prominent fire insurance companies formed the National Board of Fire Underwriters (NBFU) to deal with the many problems plaguing the industry. Originally formed as an association to stabilize insurance rates and commissions and look after the interests of the stock fire insurance industry, the board evolved into a leading developer and promoter of many fire protection and prevention concepts still in use today. In addition, organizations such as the **National Fire Protection Association (NFPA®)** and UL formed with the support of the NBFU, and the NBFU either wrote or published the first electrical, building, and fire prevention codes.

In the early to mid-1900s, three regional model code organizations independently formed and eventually published their own codes to be used within their regions. Although the NBFU was still a prominent player, the Building Officials and Code Administrators International (BOCA), the International Conference of Building Officials (ICBO), the Southern Building Code Congress International (SBCCI), and the NFPA® were becoming more influential and dominant. Over time, these organizations expanded their roles in the code development process to become the primary writers, promoters, and promulgators of model codes and standards. This eventually led to the NBFU discontinuing publication of its building and fire codes in 1976.

By the mid-1990s, BOCA, ICBO, and the SBCCI merged to form the **International Code Council® (ICC)**, and it and the NFPA® are the two prominent organizations that develop and publish the model building and fire codes available for adoption by local, state, and federal government agencies. In addition, the NFPA® develops and publishes many of the standards used by government, design, and industry professionals. The work of these organizations has led to a national code development process that addresses the issues arising in communities desiring to maintain fire-safe buildings and environments.

Model code organizations are made up of groups or individuals including code officials, design professionals, consultants, trade associations, builders, contractors, manufacturers, suppliers, industry experts, government agencies, and other interested parties. These groups and individuals come together to propose, debate, reject, or adopt changes to the existing codes and standards. The purpose of the model code organizations has always been to develop and maintain building, fire, mechanical, plumbing, electrical, and other related codes, standards, and recommended practices independent of the influence, affiliation, and pressure exerted by special interest groups. While the model code organizations have staff to support the process, the organization's membership performs the code development work and then votes on the proposed new codes or changes to existing codes. This process has worked reasonably well, and both the NFPA® and ICC remain at the forefront of code regulation by determining the best and safest methods to design, install, handle, and regulate the materials and processes used to construct a building.

International Code Council®

The ICC evolved in the early 1990s because of two political events with international implications. First, the ratification by the U.S. government of the North American Free Trade Agreement (NAFTA) allowed tariff-free trade among Mexico, Canada, and the United States. Second, the formation of the European Common Market and European Union (EU) eliminated trade boundaries between many European countries, developed a common currency, and formed a large regional political entity with the purpose of promoting European and global economies. In addition, the EU established a committee on construction that standardized construction practices and materials. These events put the regional code development system under scrutiny because of technical discrepancies between each of the model codes (Diamantes 2015, 10). Without uniform codes, the competitive advantage in manufacturing and construction could be lost when working from region to region in the United States and, potentially, throughout the world. One set of codes would permit code officials, design professionals, and contractors to work from the same codes no matter where they were in the country. In addition, it would allow manufacturers to focus on research and development to compete in the world market instead of spending their efforts trying to meet three different design standards in the United States (International Code Council® 2005, 2).

To overcome these problems, the BOCA, ICBO, and SBCCI formed the ICC in 1994 to develop and maintain the International Code Series. In 1996, the ICC started the process of developing and publishing the new, collective ICC Model Code Series. An agreement among the three organizations permitted each to continue publication of its own codes until the entire series of the new international codes was published. By 2000, the code series was completed, and all organizations stopped independent publication of their codes.

The ICC Code Development Process

The ICC code development process is open to anyone but structured to avoid domination by proprietary interests. All meetings are open to the public and held in the public forum. All actions and the reasons for those actions are published. Individuals and organizations with a material interest in the outcome of the code development process participate in the committees that study these issues, but at least one-third of each committee is composed of government officials. Government-affiliated ICC members vote on the code changes brought forward by the committees. The ICC divides its 15 published codes into separate review groups. Starting 3 years prior to the next code cycle publishing date, the first set of codes in Group A are vetted by the assigned review committees. The following year the Group B codes are vetted by the assigned review committees. During the last year of the cycle, the Group C code vetting takes place. At the end of the 3-year cycle, all of the codes are prepared for publication with an expected publishing date set 6 to 8 months before the next code cycle starts. There are a number of steps to the ICC code development process, and a discussion of each step follows **FIGURE 2-1** (International Code Council® 2018, 9–10, 15, 21–22).

Step 1—Submit Code Changes. Anyone may submit a proposed code change, but it must be received by the announced due date within the review cycle to be considered. As part of the proposed code change, the submitter must provide the reason for the change, supporting documentation, bibliography, copyright

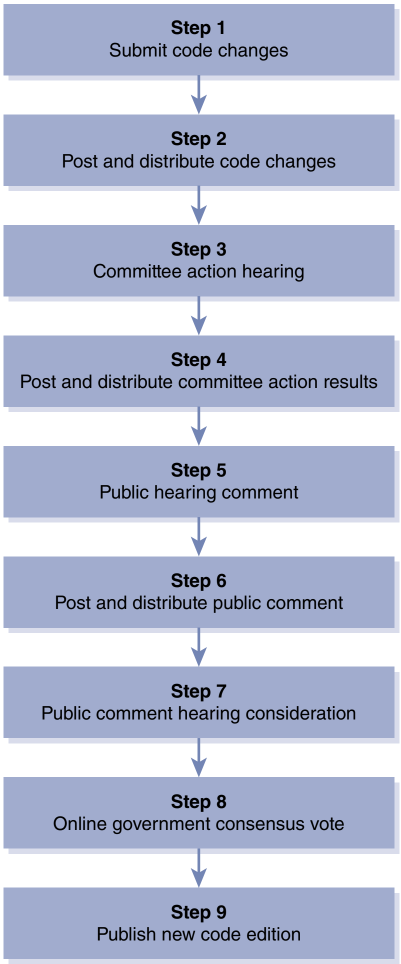

FIGURE 2-1 International Code Council® code development process.

release, and the cost impact statement. Once they are submitted, the ICC staff will review the proposed code changes prior to public review to make sure the form and format are correct, coordinated with other codes, properly documented, and substantiated and any copyright issues are resolved (International Code Council® 2018, 29, 31–32).

Step 2—Post and Distribute Code Changes. After the ICC staff has reviewed the documents, the ICC posts the recommended changes that will be presented at the code development public hearing between 30 and 45 days in advance of the hearing. This advance posting provides adequate time for review of the changes by all interested parties (International Code Council® 2018, 33).

Step 3—Committee Action Hearing. Public hearings of the proposed changes take place at the ICC national conferences. These hearings provide interested parties the opportunity to express their views to the code development committees. After all parties have presented their views on the specific change, the code development committee responsible for a particular code will vote to approve as submitted, approve as modified, or disapprove. If there are motions stating disagreement with the committee actions, a second motion is required to move the process forward. Approximately 2 weeks after the hearing, the assembly motions are voted on by the members, and any successful assembly action results in an automatic public comment to be considered at the public comment hearing (International Code Council® 2018, 34–37).

Step 4—Post and Distribute Committee Action Results. All hearing results are posted on the ICC website approximately 30 days following the hearing (International Code Council® 2018, 38).

Step 5—Public Hearing Comment. The public hearing comment step provides an opportunity for any interested parties to consider specific disagreements to the results of the public hearing and prepare comments for the public comment hearing. Any comments must state why there is disagreement with the committee and assembly action. In addition, the comments must propose revisions to the code change that are within the scope of the original proposal and provide the reasons with supporting documentation (International Code Council® 2018, 39–41).

Step 6—Post and Distribute Public Comment. As before, the ICC staff receives public comment by the published deadline and reviews these comments to ensure appropriate submission and format procedures. Once released, the published results become the agenda for the public comment hearing. Publishing takes place between 30 and 45 days prior to the public comment hearing (International Code Council® 2018, 42).

Step 7—Public Comment Hearing Consideration. Consideration of all the proposed changes takes place at the public comment hearing. The hearing is open to the public, and anyone may participate in the floor discussion. However, once all discussion, testimony, and motions are completed, only active ICC governmental members may cast a vote. By permitting only active governmental members to vote on the final action, the ICC considers the process open, fair, and objective with no proprietary interest serviced (International Code Council® 2018, 43–44).

Step 8—Online Governmental Consensus Vote. This is the final step before publishing a new edition of the code. Approximately 2 weeks after the close of the public hearing, online voting takes place with the results combined with votes cast at the public comment hearing. Depending on the committee action to approve as submitted, approve as modified, or disapprove, either a simple majority or two-thirds majority is required to pass a proposed code change. When a proposed change does not receive any of the required majorities, the final action records as disapproved (International Code Council® 2018, 45–47).

Step 9—Publish New Edition. As soon as practicable, the votes are tabulated and the final action on all proposed changes is published and made available to interested parties, with any changes in the code text published in the next supplement or new edition of the model code (International Code Council® 2018, 48).

The mission of the ICC is to provide high-quality codes, standards, products, and services for all those involved in the safe construction of buildings and structures (International Code Council® 2018, 4). As such, it is easy to see the need for the many steps in the code development process to ensure an open, balanced, and consensus-based process.

National Fire Protection Association

The origin of the NFPA® dates to 1895. At the time, there were nine different fire sprinkler system design and installation standards within 100 miles of Boston, Massachusetts, and it was becoming a problem for the plumbers who installed fire sprinkler systems to keep track of where each standard applied (Richardson et al. 2003, 255). A group of men affiliated with stock fire insurance organizations and a pipe manufacturer decided to solve the problem by establishing a uniform standard. Impressed with the work of Frederick Grinnell, a pioneer in manufacturing fire sprinkler products, and the success of Factory Mutual (now FM Global® or FM) at underwriting properties with fire sprinkler systems designed and installed from a consistent and proven standard, the group published the *Report of Committee on Automatic Sprinkler Protection.* During a subsequent meeting of the group in late 1896, articles to form a new association to deal with fire protection issues were outlined and reviewed. The *Articles of the Association* was adopted by the group and established the organization known as the National Fire Protection Association (National Fire Protection Association 2018). The 1896 publication, which established rules for the installation of fire sprinkler systems, eventually was renamed NFPA 13, *Standard for the Installation of Sprinkler Systems*. Today, it is the most widely used fire sprinkler standard.

Originally, membership was limited to stock fire insurance organizations and their representatives. However, by 1904 many trade, engineering, and industrial associations, organizations, and individuals not affiliated with the insurance companies were able to join (Richardson et al. 2003, 257). As membership in the NFPA® grew, the association's role started to expand into providing public education, engineering publications, disseminating fire research information, and, most importantly, developing codes and standards.

Currently, the NFPA® publishes and maintains more than 300 safety codes and standards that are revised and completely updated every 3 to 5 years. The codes and standards cover fire, building, electrical, process, and life safety issues. Approximately 9000 volunteers work on more than 250 technical committees to administer this process (National Fire Protection Association 2019). The NFPA's 50,000 members come from more than 100 nations and include individuals from government, the fire service, business, industry, health care, insurance, design, trade, manufacturing, supply companies, and professional associations (National Fire Protection Association 2019). All of these entities work to fulfill the NFPA® mission to promote science and improve fire protection, prevention, and electrical safety.

The NFPA® process starts with the NFPA Board of Directors, which oversees all activities including the rules and regulations regarding code and standards development. The board appoints 13 people to the Standards Council; this group is responsible for the code and standards development activities, rules, regulations, and appeals. In addition, the Standards Council appoints and oversees the activities of the technical committees that are the primary consensus bodies that develop and revise the codes and standards. When the Standards Council receives a proposal for a new code or standard, it will evaluate the merits and, if appropriate, request the following information:

- Comments on the proposed project
- Organizations that may be involved or are interested
- Available resource material
- Indication of willing participants if the project is approved (National Fire Protection Association 2016, 3–4)

Once the Standards Council receives and reviews the comments concerning the proposed code or standard development project, it will determine whether the project should move forward. If approved to move forward, an existing technical committee or a newly created technical committee will start developing the code or standard. The technical committee members represent the insurance industry, installation and maintenance organizations, manufacturers, end users, special experts, labor organizations, research and testing organizations, consumers, and enforcing authorities. To avoid overrepresentation from any one group, no more than one-third of the members on the technical committee can be from the same interest category. Committee appointments rest on an individual's technical knowledge, standing in the professional community, commitment to public safety, and ability to represent a viewpoint of a group or interested people (National Fire Protection Association 2016, 5). For a technical committee to take action on a proposal, the voting members must reach a consensus.

The NFPA® Code Development Process

There are four basic steps to the NFPA® code development process **FIGURE 2-2**. The same steps apply when developing a new document or revising the new edition of an existing document. Depending on the type of document and code cycle, the process can take approximately 101 or 141 weeks to complete. A discussion of each step follows.

Step 1—Public Input Stage. During the public input stage, all interested parties are asked to submit written proposals for revisions to existing standards or committee-approved new standards. Once submitted, the proposals are evaluated and voted on, and then a first draft report is issued (National Fire Protection Association 2016, 7).

Step 2—Public Comment Stage. In this step, the responsible technical committee meets to review and take action on all of the submitted comments resulting from the first draft report. The committee will evaluate all public comments, take action, and respond to the public comments. The results are published as a second draft report to be voted on by the committee. The results of these actions are posted for public review so that anyone who disagrees has a chance to make a motion to amend at the next stage of the process. If there are no public comments and the committee agrees that no revisions are necessary, the proposal can go directly to the Standards Council to be issued (National Fire Protection Association 2016, 8).

Step 3—NFPA® Technical Meeting. At this stage, anyone not satisfied with the results of the second draft report can file a *Notice of Intent to Make a Motion*. The motion provides an opportunity to change the results of the recommendations of the committee published as the second draft. This notification places the issue in front of the NFPA® membership at the annual meeting where the motion can be considered and debated at the technical meeting. However, to be included as part of the meeting agenda, the motion must be approved to move forward and follow proper procedures regarding what type of motion is permitted and when and who can make the motion. Once debated and voted on, any successful motion must be reviewed and approved by the responsible committee (National Fire Protection Association 2016, 9–10).

Step 4—Council Appeals and Issuance of Standard. When the Standards Council meets to issue the new standards, it also hears appeals. The council reviews all activities associated with the decisions to ensure procedures and rules were followed and the process was fair throughout. Once the council determines the disposition of all appeals, if appropriate, the standard proceeds to be issued as an official NFPA® standard. The decision is final and effective 20 days after approval. However, the decision may be subject to limited review by the Board of Directors. Proposals that do not require any action or debate are sent to the Standards Council and issued as consent standards (National Fire Protection Association 2016, 11).

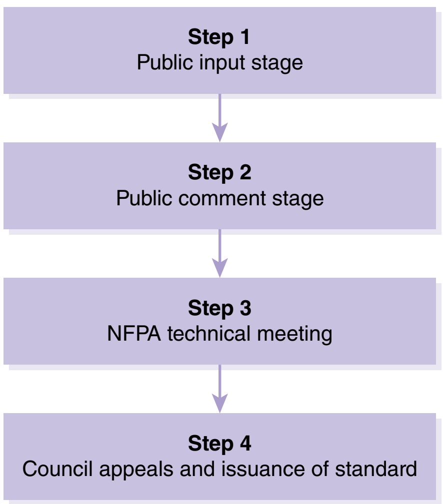

FIGURE 2-2 National Fire Protection Association (NFPA®) code development process.

The NFPA's mission is to advocate for "consensus standards, research, training, and education on safety related issues" (National Fire Protection Association 2016, 2). The NFPA's code development process promotes open and fair procedures, in which anybody with an interest is encouraged to participate throughout the development cycle. Although anybody can participate and provide input during the process, the responsibility to decide on the merits of any change or proposal ultimately rests with the technical committees that act as the principal consensus body.

Referenced Standards

The model codes cover a wide variety of building, fire prevention, and life safety topics. In order to thoroughly address all important and related issues, the code writers recognize the necessity of looking outside their organizations for additional and relevant information. To ensure utilization and adoption of the best methods, standards, and practices, the developers of the model codes reference documents published by other nationally recognized organizations that have specific knowledge and expertise to meet the required performance characteristic or design intent. The model codes call these documents **referenced standards**. When a standard is developed, it must go through the consensus process, be performance based, not specify products or materials, be mandatory, and be readily available before it is considered adoptable. Referenced standards provide specific information related to materials, methods, procedures, equipment design, and installation requirements. When a standard is referenced in a model code, it becomes a part of the code and is enforceable.

The relationship between the model codes and referenced standards is simple: The model codes determine "what to do and where," and the referenced standard explains "how to do it." For example, when an architect designs a new high-rise building, both the NFPA® and ICC building codes require the installation of an automatic fire sprinkler system throughout the building. In this example, both model codes state "what to do and where": install an automatic fire sprinkler system in a high-rise building. In addition, both codes state that NFPA 13, *Standard for the Installation of Sprinkler Systems,* shall be used to design and install the system. NFPA 13 is the design and installation standard referenced by both codes that provides the "how to do it" part of the relationship.

This practice is in the best interest of all parties; instead of trying to write thousands of pages of additional code and text, the model code organizations are able to reference specific documents to facilitate design and installation requirements for a project. Without these standards, effective enforcement would not be possible. The 2018 edition of the *International Building Code® (IBC®)* lists 55 organizations as providers of referenced standards. The 2018 edition of NFPA 5000®, *Building Construction and Safety Code®*, lists 41 organizations as providers of standards. Both model code organizations rely on standards published by NFPA® when dealing with the different design, installation, inspection, testing, and maintenance requirements for fire protection systems. Various NFPA® and ICC 2018 codes reference a number of NFPA® fire protection system–related standards that are found in **TABLE 2-1**.

> **TIP**
>
> Both the ICC and NFPA® rely on many of the same outside organizations for their referenced standards. However, there are differences between each model code; and the referenced standards listed within each model code are specific to that model code.

Amendments

Based on years of data and experience with building and fire problems, the model codes and standards establish a level of performance and risk that is acceptable to all involved in the code development process. However, the model codes are the *minimum* acceptable level of performance or risk; therefore, there may be instances when the code is not adequate for the circumstances and it becomes necessary to apply stricter or additional performance standards to deal with the risk. Generally, the level of performance and acceptable risk meets the needs of a jurisdiction, but there may be a situation in which a problem needs special review and consideration. Perhaps the problem is unique to the jurisdiction, in which case the community may choose to establish safety and building standards that exceed the normal accepted level. Alternatively, an organization such as an insurance carrier may analyze a risk and determine that a more demanding requirement is necessary in order to qualify for coverage. Although most governmental organizations do not try to write comprehensive building and fire codes, to some degree, most adopt and then amend model codes to deal with the associated hazards and risks. Under these circumstances, those with the authority may decide to amend the model code and write different requirements. If the **code amendment**

TABLE 2-1 List of Referenced Fire Protection System Standards

NFPA® Standard	NFPA 1, Fire Code	NFPA 101®, Life Safety Code®	NFPA 5000®, Building Construction and Safety Code®	International Building Code® (IBC®)	International Fire Code® (IFC®)
NFPA 4, *Standard for Integrated Fire Protection and Life Safety System Testing*	X	X	X		X
NFPA 10, *Standard for Portable Fire Extinguishers*	X	X	X	X	X
NFPA 11, *Standard for Low-, Medium-, and High-Expansion Foam*	X	X	X	X	X
NFPA 12, *Standard on Carbon Dioxide Extinguishing Systems*	X	X	X	X	X
NFPA 12A, *Standard on Halon 1301 Fire Extinguishing Systems*	X	X	X	X	X
NFPA 13, *Standard for the Installation of Sprinkler Systems*	X	X	X	X	X
NFPA 13D, *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes*	X	X	X	X	X
NFPA 13R, *Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies*	X	X	X	X	X
NFPA 14, *Standard for the Installation of Standpipe and Hose Systems*	X	X	X	X	X
NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection*	X	X	X		X
NFPA 16, *Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems*	X	X	X	X	X
NFPA 17, *Standard for Dry Chemical Extinguishing Systems*	X	X	X	X	X

(*continued*)

TABLE 2-1 List of Referenced Fire Protection System Standards (*Continued*)

NFPA® Standard	NFPA 1, Fire Code	NFPA 101®, Life Safety Code®	NFPA 5000®, Building Construction and Safety Code®	International Building Code® (IBC®)	International Fire Code® (IFC®)
NFPA 17A, *Standard for Wet Chemical Extinguishing Systems*	X	X	X	X	X
NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection*	X	X		X	X
NFPA 22, *Standard for Water Tanks for Private Fire Protection*	X				X
NFPA 24, *Standard for the Installation of Private Fire Service Mains and Their Appurtenances*	X		X		X
NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*	X	X			X
NFPA 70®, *National Electrical Code®*	X	X	X	X	X
NFPA 72®, *National Fire Alarm and Signaling Code®*	X	X	X	X	X
NFPA 92, *Standard for Smoke Control Systems*	X	X	X	X	X
NFPA 96, *Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations*	X	X	X		X
NFPA 750, *Standard on Water Mist Fire Protection Systems*	X	X	X	X	X
NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*	X	X	X	X	X
NFPA 2010, *Standard for Fixed Aerosol Fire Extinguishing Systems*	X			X	X

establishes a higher level of required performance, the amendment supersedes the model code and possibly the requirements found in a referenced standard. Usually, this process takes place at the state or local level and requires legislative authority to enact. Therefore, it is important to know who in a state or local jurisdiction establishes the requirements and how the process works with regard to the adoption and amendment of model codes for building, fire, and life safety.

Code-Required Fire Protection Systems

One of the most frequently asked questions of local fire and building departments is "Why do some buildings have fire protection systems installed and others do not?" The technical answer is the building codes that are in effect at the time of the design, approval, and construction and the specific **use** and **occupancy** classification for the structure establish the requirement to install fire protection systems. In other words, the code requirements in effect at the time of construction, the function of the structure, and the inhabitants who will be using the structure are the primary determinants for whether fire protection systems are required. **TABLE 2-2** lists the major use and occupancy classifications found in the model codes, but there are some use and occupancy classifications that have subclassifications. For example, the IBC® lists five subclassifications for assembly that outlines the permitted use and occupancy conditions for each; NFPA 101® lists requirements for assembly as either new or existing; and NFPA 5000® provides general requirements for their definition of an assembly use and with each occupancy.

Other factors come into play as well including hazards and conditions within the structure; how far people must travel to exit a building; what level or floor in a building or structure they occupy; the creation of a fire barrier between use areas; the protection of an opening in a wall; the size of the use or occupancy area within a building; and the number of occupants, products, commodities, and processes. However, the practical answer for why some buildings have fire protection systems and others do not is that current building code requirements for fire protection systems in certain use and occupancy classifications are primarily based on past fire experiences **TABLE 2-3**.

Those interested in solving the fire problem have documented fires in which there was significant loss of life, property, or both. Upon investigation of this history, many of the same factors or conditions played a significant role in the loss, including the building use and occupancy, the materials used to build the structure, the distance to the exits, the capacity of the exits to handle the number of people inside the structure, and the height and area of the structure. Because of these past fire experiences, building codes were changed to require the installation of fire protection systems, but in many instances, this change only affected new building construction, not existing buildings. For example, high-rise buildings built before the 1980s were not specifically required to have automatic

TABLE 2-2 ICC and NFPA® Use and Occupancy Classifications

International Code Council®—International Building Code® (2018 Edition)	National Fire Protection Association—NFPA 101®, Life Safety Code®/NFPA 5000®, Building Construction and Safety Code® (2018 Editions)
Assembly	Assembly
Business	Business
Educational	Day care
Factory/Industrial	Detention and correctional
High-hazard	Educational
Institutional	Health care
Mercantile	Health care ambulatory
Residential	Industrial
Storage	Mercantile
Utility and miscellaneous	Residential
	Residential board and care
	Storage

TABLE 2-3 Requirements for Systems Based on Occupancy Conditions

Occupancy	Relative Hazard
Assembly	Large number of people
Day care	People who need care, maintenance, supervision
Detention/Correctional	People under varied degrees of restraint or security mostly incapable of self-preservation
Educational	Large number of children
Large factory/Industrial	High fire load
Hazardous	Dangerous materials
Health care/Health care ambulatory	People mostly incapable of self-preservation due to age, physical or mental disability, or security measures not under the occupants' control
Institutional	People who are incapable of self-preservation
Large mercantile	High fire load
Covered mall	Large area, high fire load
High-rise buildings	Large area, difficult access for firefighting
Underground structures	Difficult access for firefighting

fire sprinkler systems installed. However, because of a number of catastrophic high-rise fires, high-rise buildings constructed from the mid-1980s to the present require automatic sprinkler system installation. Many high-rise buildings built before the initiation of this requirement still do not have automatic fire sprinkler systems, including a significant number of residential occupancies. Codes generally do not contain retroactive requirements when a structure has not changed use or occupancy classification from the time of construction completion, unless the code is changed at the state or local level.

Inducements to Install Fire Protection Systems

Because there is such confidence in properly designed, installed, inspected, tested, and maintained automatic fire sprinkler systems, construction codes permit some increases and reductions in other performance and construction characteristics when building a new structure. Some of the increases include longer travel distances to exits and reductions in the construction requirements for exits based on the assumption that a properly operating fire sprinkler system will offer occupants an equivalent level of protection and time for exiting before conditions become untenable. In addition, the model codes include incentives to install automatic fire sprinkler systems in buildings that would not ordinarily be required to have automatic fire sprinkler system protection. For example, when building with a combustible material such as wood, structures are limited in size, height, and the number of stories if there is no automatic fire sprinkler system installed. However, increases are permitted if the building is equipped with an automatic fire sprinkler system. These types of incentives encourage the developer or builder to maximize the use of the property, protect the occupants, and protect the building.

Model construction codes attempt to achieve a balance between the hazards posed by the structure itself,

TIP

In most jurisdictions, the building codes in effect at the time a structure is built remain in effect as long as the use and occupancy classification of the structure do not change. However, depending on the nature and level of construction, any new building construction in an existing building must conform to current code or existing building code requirements in the area of the building where the construction takes place.

TIP

As a condition of an insurance policy, many insurance companies require that commercial and industrial building owners install some type of fire protection system. Depending on the hazard, it may be that only fire detection devices are required, but most insurance-required fire protection systems include the installation of automatic fire sprinkler systems.

the combustible contents, the floor areas above and below ground level that challenge manual firefighting efforts, and the cost of construction. By incorporating fire protection systems in the design, this balance is easier to achieve.

Mission Essential

Protecting human life is essential, but another reason for a building owner to install a fire protection system is that it makes good business sense. When evaluating a fire loss, the most obvious damage is to the structure and its contents. Although the dollar figure associated with the damage to the structure and its contents is often staggering, it does not represent or account for the total loss. Loss from the interruption of business is often much greater than the damage to the structure. In the aftermath of a fire, many businesses either close or lose their competitive advantage. During the time required to rebuild or relocate, customers must find alternatives, and furloughed employees must find other jobs. Unfortunately, there may be few, if any, customers or employees left to sustain the business once it is rebuilt. Minimizing business interruption is one of the many reasons that insurance companies require the installation of fire protection systems in buildings that do not have them. For example, water damage cleanup and repair from a fire sprinkler system does not take as long and, in most cases, cost as much as fire damage cleanup and repair. Frequently, there is a good chance that the business could reopen within hours, days, or weeks following a fire if there is a fire sprinkler system in place. However, fire damage cleanup and repair can take months or years or, in some cases, may never happen.

TIP

Data compiled by NFPA® between 2010 and 2014 revealed that when fire sprinklers were installed in a building, the fire was confined to the room of origin 96 percent of the time compared to an unsprinklered building where the fire was confined 71 percent of the time (Ahrens 2017, 4).

Wrap-Up

CHAPTER SUMMARY

- Building and fire codes provide uniform and consistent standards and guidelines for all parties to ensure public safety in buildings.
- A model code is a system of rules, guidelines, methods, and regulations that is typically developed by private, not-for-profit organizations and is available to governments for adoption.
- A code is a system of rules, regulations, or laws, usually developed by government, that has statutory authority to be enforced; it establishes what a person or entity can or cannot do.
- Currently two organizations, the ICC and NFPA®, in conjunction with their membership, develop and publish model codes.
- A model code determines “what to do and where”, a referenced standard explains “how to do it”.
- The model codes establish the minimum level of performance and risk, but in some situations a problem needs special consideration and the model code does not adequately address the potentially higher risk or hazard. Under these circumstances, those with the authority write amendments to the code and write different requirements.
- It is important to know who within any state or local jurisdiction establishes the requirements and how the process works regarding the adoption of model codes for building, fire, and life safety.
- Installations of fire protection systems are generally a result of a code adopted by government to protect life and safety.
- Fire protection systems are part of code-based inducements that make the installation financially attractive, are a condition of insurance, or are an element to manage risk and ensure business continuity.

KEY TERMS

Adopt The process of officially accepting and putting something into action.

Code A standard that is an extensive compilation of provisions covering broad subject matter or that is suitable for adoption into law independently of other codes and standards (National Fire Protection Association 2018, *NFPA 1,* Section 3.2.3).

Code amendment The process of revising, changing, correcting, or improving a code.

International Code Council® (ICC) A nonprofit member-supported organization that develops and maintains construction codes that are made available to government agencies for adoption.

Model code A system of rules, guidelines, methods, and regulations typically developed through the consensus process by private, not-for-profit organizations.

National Fire Protection Association (NFPA®) A nonprofit member-supported organization that develops and maintains more than 300 codes and standards for use by any organization.

Occupancy The purpose for which a building or other structure, or part thereof, is used or intended to be used (National Fire Protection Association 2018, *NFPA 5000,* Section 3.3.446).

Referenced standard A standard that is incorporated or adopted as part of the model code and provides specific information as a guide or model regarding the performance, design, installation, inspection, testing, and maintenance requirements of systems, materials, and equipment.

Use Building code categorization of buildings and structures based on their use and the characteristics of their occupants.

CASE STUDY

While conducting a familiarization drill in a 1960s-era mercantile building that recently added a very large storage area, you notice that the original part of the building does not have an automatic fire sprinkler system, but the new addition does.

1. What are the probable factors that determined the need to install an automatic fire sprinkler system in the new storage area?
   - **A.** Products being stored
   - **B.** Size of the addition
   - **C.** Use and occupancy condition
   - **D.** All of the above
2. What is the most probable reason the old part of the building was not required to have an automatic fire sprinkler system installed when it was built?
   - **A.** Products being sold were not deemed dangerous at the time
   - **B.** Size of the original building was not big enough
   - **C.** Not required by code
   - **D.** None of the above
3. What is the most probable reason the old part of the building was not required to install an automatic fire sprinkler system when the addition was built?
   - **A.** Too expensive to install
   - **B.** Use and occupancy did not change
   - **C.** Building size did not require it
   - **D.** Both A and C
4. From a development perspective, what were the possible benefits gained by installing an automatic fire sprinkler system in the new addition?
   - **A.** Increased building size and height
   - **B.** Increased travel distances to exits
   - **C.** Increased fire resistance rates
   - **D.** Both A and B

CHALLENGING QUESTIONS

1. What is the purpose of adopting building and fire codes?
2. What is the difference between a code and a model code?
3. Identify the two most prominent model code organizations that are leading the code development process.
4. Discuss the events that led to the formation of the International Code Council® in the 1990s.
5. What does it mean for an agency to adopt a code?
6. Describe the relationship between a model code and a referenced standard.
7. Why would a jurisdiction amend a model code?
8. Why are referenced standards so important to the code development process?
9. Discuss the pros and cons of the ICC and NFPA® code development process. Do you feel that each organization has adequate representation from all of the appropriate parties throughout the process and that each arrives at a true consensus? What suggestions would you make to improve each organization's methods?
10. What is the most important factor when determining the installation requirements for a fire protection system in a structure?

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SECTION

2

Fire Alarm and Detection Systems

CHAPTER 3

Fire Alarm and Detection Systems

Fire Alarm System Components and Functions

LEARNING OBJECTIVES

At the conclusion of this chapter, you will be able to:

- Describe the purpose of a fire alarm system.
- List five functions fire alarm systems provide.
- List and describe the three types of fire alarm signals.
- Discuss the characteristics of conventional fire alarm system technology.
- Discuss the characteristics of addressable fire alarm system technology.
- Discuss the functions of a fire alarm control unit/panel and annunciator panel.
- List and describe the different components that make up a fire alarm system.
- List and describe devices that interface with a fire alarm system to supervise the condition of other fire protection systems.

Case Study

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On March 14, 2018, a fire broke out in a Horn Lake, Mississippi home, resulting in the death of one person and injuries to five others. Around 7:00 AM, one of the residents awoke to a house filled with smoke and was forced to exit through a window. He attempted to fight the fire with a hose, but his efforts were unsuccessful. When fire fighters arrived, they encountered thick smoke and intense heat that required the use of a thermal imaging camera to locate and rescue the other residents. Upon investigation, an overloaded electrical circuit appeared to be the cause.

Significant to this event was the lack of any warning to the occupants from a smoke alarm. One was located in the home, but it was stored in a box, disconnected, and without a battery. The resident who attempted to fight the fire stated that the victim probably removed the detector because of it activating every time a person took a shower.

In the January 2019 National Fire Protection Association (NFPA®) report *Smoke Alarms in U.S. Home Fires*, 2016 data from the U.S. Fire Administration's National Fire Incident Reporting System and NFPA's annual fire department survey stated that the risk of dying in a fire decreased by more than half in homes that had working smoke alarms as opposed to those homes that did not have a smoke alarm or had a smoke alarm that did not operate. When a smoke alarm was present but did not operate, two-thirds of fire deaths occurred in homes with only battery-powered smoke alarms. The high number of deaths where battery-only smoke alarms were installed but did not operate is troubling when reviewing the reasons for failure. The majority of failures were due to missing, disconnected, dead, or discharged batteries. In the report, NFPA® states that "people are most likely to disable smoke alarms because of nuisance activation." No matter the type of detector, many nuisance alarms are directly related to cooking, steam from showers, and the chirping the smoke alarm sounds when the battery power is low. A considerable number of these issues could be easily resolved by relocating a smoke alarm away from the nuisance source and educating the public through community outreach. Topics of discussion should focus on the life expectancy of certain batteries that might need to be changed about every 6 months, the use of a long-life battery, and the fact that the chirping sound is a warning that the battery needs to be replaced.

There are many other factors related to smoke alarm performance or nonperformance, the number of deaths and injuries, and the ability of the occupants to react to a smoke alarm and take the appropriate action. However, the most important issues to remember are smoke alarms need to be installed and remain installed to work and when a smoke alarm is installed and properly maintained, the chances of surviving a fire more than doubles.

1. Does your community have a program to determine which residential dwelling units and homes do not have smoke alarms?
2. What measures can be undertaken to provide smoke alarms to residential dwelling units and homes that do not have smoke alarms?
3. With so many installed smoke alarms only powered by a battery that have failed to operate, what can be done to decrease the number of unit failures due to a missing, disconnected, or dead batteries?
4. What measures can be undertaken to ensure that any type of smoke alarm is ready to function when needed?

Sources: Modified from Holley, Jessica. "Man Killed, 5 More Injured in Horn Lake House Fire." *WMC Action News 5*, March 14, 2018. https://www.wmcactionnews5.com/story/37724205/man-killed-6-more-injured-in-horn-lake-house-fire;

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Introduction

A person's chance of surviving a structure fire is dependent upon the amount of time that passes between the start of the fire, the person's realization there is a fire, and the associated evacuation time. Even under the best circumstances, a person usually has very little time to evacuate before the fire becomes dangerous. Installation of a fire alarm system provides notification in a fire emergency and is critical to an individual's chance of survival. For this reason, many use-group and occupancy conditions require some type of fire alarm system to alert occupants of the situation and potential danger.

A **fire alarm system** is a group of interconnected components and devices that are designed to cause a response by building occupants. The three basic components of a fire alarm system are the initiating device, the notification appliance, and the control panel. Initiating devices may be automatic, such as a smoke detector, or manually operated, such as a manual fire alarm box. Once the initiating device activates, it triggers one or more notification appliances, including bells, horns, or strobe lights, to alert building occupants to evacuate.

In addition to occupant notification, fire alarm systems are capable of sending a signal to on- or offsite locations where trained staff receive the signal and take appropriate action that will involve notification of building, property, or fire department personnel. The fire alarm system may also send a signal to other building fire and life safety systems to initiate other life safety functions. These functions may include capturing elevators, unlocking exit doors, starting fans, closing smoke dampers, pressurizing stair towers and elevator shafts, and de-energizing magnetic door hold-open devices to compartmentalize an area of a building. Fire alarm systems also interface with and monitor the status of other fire protection systems and react when there is a change in the normal ready condition of the system, a system activation, or a problem related to the electrical or electronic part of the fire protection system. Once first responders arrive, most systems provide critical information, including the alarm type and location of alarm origin.

There are many different components necessary to ensure full functionality and operational capability of a fire alarm system during a fire emergency. Some systems only have a few components that perform basic tasks, whereas other systems have many interconnected components that are capable of controlling related fire protection or life safety systems within a building. No matter the number, each component installed has a place and purpose in the system and, therefore, must be evaluated and tested for listing and approval by a nationally recognized testing laboratory such as UL, FM Global, or Intertek.

The ability to recognize the components of a fire alarm system and to have knowledge of their operational potential leads to a better understanding of the system's overall capabilities. This chapter focuses on different fire alarm system components, how they function, and the different types of signals generated by these systems.

Fire Alarm Control Unit/Panel

One of the most important parts of any fire alarm system is the **fire alarm control unit**, or as it is more frequently called, the fire alarm control panel, which is often described as the "brain" of the system. Over the past 45 or so years, fire alarm control panel technology has evolved from simple, single zone, relay-type units that ring one or more bells to logic circuit-type multiple zone units that provide additional system information and capabilities to sophisticated microprocessor-based software-driven panels that interface and control other building and life safety systems.

Many of the early-generation fire alarm control panels used **conventional technology** to link to manual fire alarm boxes and bells to provide coded or noncoded alarm signals for evacuation **FIGURE 3-1**. The earliest designs used two-wire circuits to establish initiating device and notification appliance zones. Depending on the arrangement of the wiring and devices, a break in a wire could render any device beyond the

FIGURE 3-1 An early-generation conventional fire alarm control unit.

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break inoperative. A number of these panels are still in service, and many continue to provide reliable service.

The next generation of conventional technology panels featured modular equipment with smaller electronic components, logic or relay circuits, two- and four-wire circuits to support initiating devices and notification appliances, and expanded performance and system monitoring capabilities **FIGURE 3-2**. The four-wire systems provided a higher level of reliability because the setup typically allowed for two wires to power the device and two to initiate the alarm, whereas in most other wiring configurations, a break in the wire or a device failure would disable other devices from operating. Again, many of these panels are still in operation and continue to perform when routinely serviced, maintained, and tested. However, the desire and ability to install and support these panels are rapidly declining as technology improves and manufacturers replace their older equipment with new products; this causes technological obsolescence, lack of parts, higher maintenance costs, and a lack of qualified technicians to service the older equipment. The good news is that when a conventional panel requires replacing, in some instances, many of the new-generation panels can be installed with existing two- and four-wire systems that utilize interface modules and software to communicate with the field devices so entire systems do not have to be replaced.

Today, fire alarm control panels utilize state-of-the-art electronics, microprocessors, and intelligent software that provide specific information concerning device identification and alarm location and type.

FIGURE 3-2 A later-generation conventional fire alarm control unit.

Although many different terms are used to describe this technology, it is commonly referred to as **addressable technology**, **intelligent technology**, or **multiplex technology**. Addressable/intelligent technology is very versatile, able to support all sizes of fire alarm systems, and extremely valuable to first responders, inspectors, building engineers, and service technicians because information concerning the specific initiating device—such as the exact location of the device and, in some instances, the associated problem—is immediately available **FIGURE 3-3**.

TIP

The desire and ability to install and support conventional technology systems are rapidly declining as technology improves and manufacturers replace their older equipment with new products; this causes technological obsolescence, lack of parts, higher maintenance costs, and a lack of qualified technicians to service the older equipment.

The addressable fire alarm control panels constantly monitor the integrity of the system circuits and devices, process manual and automatic input signals from the initiating devices, drive the notification

FIGURE 3-3 An addressable/intelligent fire alarm control unit.

appliances, provide an interface to control or activate other fire protection and building systems in a fire emergency, and provide the **power supply** to support all of the system devices.

Two independent and reliable sources of power are required to supply a fire alarm system. Typically, the main or primary source of power is supplied by a power utility. However, primary power could be supplied by an engine-driven generator or equivalent that is under the constant attention of a trained operator. Once the primary power enters the facility, it must be protected from physical damage; it must be on a dedicated circuit supplying the fire alarm control panel; access to the circuit must be controlled; and the circuit must be identified. While the earliest fire alarm control panel designs used 120 VAC (volts alternating current) to power the system, most modern panels take the line voltage supplied by the utility and convert the voltage to 24 volts direct current (VDC) through the power supply circuitry. Often, the backup or secondary source of power comes from rechargeable storage batteries, an engine-driven generator, or a combination of both batteries and engine-driven generator. If storage batteries are used, they must have the capacity to sustain power for 24 hours in normal ready mode and 5 minutes in full alarm mode at the end of the 24-hour loss-of-power period (National Fire Protection Association 2019, *NFPA 72,* Section 10.6.7.2.1). These requirements differ for emergency voice alarm communications systems and mass notification systems, for which 15 minutes of power in full alarm mode is required at the end of the 24-hour loss-of-power period (National Fire Protection Association 2019, *NFPA 72,* Sections 10.6.7.2.1.2, 10.6.7.2.1.7). When a generator is used to provide the power, the generator must have 4 hours of battery capacity (National Fire Protection Association 2019, *NFPA 72,* Section 10.6.7.3.1). No matter the secondary source, power transfer must be automatic and seamless; not allow for loss of system function, delay or interrupt signals; and take place within 10 seconds (National Fire Protection Association 2019, *NFPA 72,* Section 10.6.6).

Through constant monitoring of the system power, wiring, circuits, and devices, the fire alarm control panel is able to initiate the appropriate type of signal to evacuate the building, investigate an integrity problem with the system, or investigate a condition outside the normal operating parameters.

Circuits and Wiring

In order for a fire alarm system to work, there has to be some method tying together the initiating devices, notification appliances, fire alarm control panel, and other internal and external components and systems. Approved methods include fiber-optic cable and bidirectional wireless communication, but most system installations still use wire as the primary connection method. Installation of wire must conform to the requirements found in NFPA 70®, *National Electrical Code®* (NEC), and NFPA 72®, *National Fire Alarm and Signaling Code®*.

The NFPA 70® section on fire alarm systems provides information concerning circuit types, power requirements, and limitation for the circuits; the type and size of wire permitted; and in conjunction with NFPA 72® requirements, installation wiring methods to ensure that the wire maintains integrity and is able to survive in a fire or other event that could inhibit the fire alarm system from operating. NFPA 70® designates fire alarm circuits as either *power-limited*, meaning that the circuit receives power from a limited power source that is typically 12 or 24 VDC, or *non-power-limited,* for which the power source shall not exceed 600 volts, nominal. In addition, it designates how the circuits and wiring must be labeled and identified so that the proper type of wire is installed as listed or approved.

NFPA 72® discusses circuit classification and the types of circuits installed as related to the systems and devices. Three different types of circuits are used with conventional and addressable technology-based systems: the **initiating device circuit (IDC)**, **signal line circuit (SLC)**, and **notification appliance circuit (NAC)**. Initiating device circuits are installed with conventional technology systems, signal line circuits are installed with addressable technology systems, and notification appliance circuits are installed with both.

Conventional technology systems use initiating device circuits to provide the power and monitor the wire integrity within a fire alarm zone. Also known as a zone-module system, the conventional system devices are in zones that connect to zone cards or circuit modules. The conventional systems are set up where one or more devices such as a smoke detector can be in a zone within a building. For example, if a smoke detector in a zone activates, the information provided to the fire alarm control panel only communicates the zone, not the specific smoke detector that activated. This also means that only the wiring is monitored for problems, not the smoke detectors. In this example, the smoke detectors are switches that are on or open, but when they are off or closed, they short the circuit, sending a signal to the fire alarm control panel to initiate an alarm.

Addressable technology systems connect the field devices (addressable initiating devices and signal line circuit interface modules) to signal line circuits so the microprocessor software recognizes the device on the circuit and the signal the device is sending back to the fire alarm control panel. Simply stated, the signal line circuits provide a communication path for data exchange between the fire alarm control panel and field devices; the power for the devices is also supplied through the circuit. Each field device is programmed with a specific address so the panel knows the device it is communicating with and the status of the device. The panel constantly communicates with the field devices through the SLC that is constantly sending out a status request to all the devices. Basically, the panel is asking if the device is OK, and if it is OK, the system status stays ready. However, if the device has a change in status, it will respond with the appropriate signal.

In order for the notification appliances attached to a fire alarm system to operate, they must be powered from the fire alarm control panel or a power expander plan. This is accomplished with notification appliance circuits. The normal condition for an NAC is the supervisory mode, where the power is sent through the wire to make sure the wire maintains integrity; in other words, there are no ground faults, shorts, or broken wires. However, once an alarm is initiated, the power switches to the notification appliances to provide visual and audible notification signals.

Both conventional and addressable technology systems use two- and four-wire wiring arrangements. When four wires are used to connect the components, they are designated as a Class A pathway because the wiring configuration provides an alternate pathway for the signals to reach all the devices. For example, if there is a single ground fault or open circuit on the wire, there is an alternative pathway to reach the other devices beyond the affected device. When these systems use two wires, they are designated as a Class B pathway because there is no redundant or return pathway for the wire to go back to the fire alarm control panel. As previously discussed, devices beyond single-fault conditions on a two-wire circuit will not operate.

TIP

Circuit integrity and survivability requirements and guidance are found in both NFPA 70® and FPA 72®.

Types of Fire Alarm Signals

From an early age, most people learn to evacuate a building if they hear a fire alarm sound. However, not all of the audible and visible information communicated by the fire alarm system means there is a fire.

TIP

NFPA 70® lists different designations for power-limited and non-power-limited wire and cable that identify where the wire or cable can be installed, but remember that there are exceptions that permit installation beyond the designation.

- FPLP: Power-limited plenum-rated fire alarm cable can be installed in plenums or other similar spaces. This cable must meet strict flammability requirements and must have low smoke generation characteristics.
- FPL: Power-limited non-plenum-rated fire alarm cable is a general purpose cable that is not rated for plenum spaces.
- FPLR: Power-limited riser-rated fire alarm cable is installed where vertical cable runs are required. This cable must have low flammability, but smoke generation characteristics can be higher than those for a plenum-rated cable.
- NPLF: Non-power-limited fire alarm cable is for general use but not for plenum, riser, ducts, or spaces where there is environmental air.
- NPLFP: Non-power-limited fire alarm plenum cable can be installed in plenums, ducts, and other similar spaces that must be fire resistant and must have low smoke generation characteristics.

TIP

Not only are there Class A and B pathway designations, NFPA 72® lists additional pathways as Class C, D, E, N, and X. The designations are determined by the performance requirements with one, Class E, listing only one condition and another, Class X, required to meet seven conditions.

TIP

Signal line circuit interface modules connect to nonaddressable devices such as a water flow switch so that the device can communicate with the addressable fire alarm control panel. These devices are also called zone addressable modules, monitor modules, or popits.

Sometimes, a local signal sounds at the fire alarm panel to indicate a system integrity problem or to indicate that the normal operating parameters of the system have changed. Although these signals are local to the panel and do not sound an alarm throughout the building, they are sometimes mistakenly interpreted as a fire alarm warning that results in a call to the fire department. A discussion of the different types of signals generated by fire alarm control panels, their purpose, and the different levels of response associated with these signals follows.

Alarm Signals

When an **alarm signal** sounds in a building, it is alerting occupants there is a fire emergency. The alarm signal should spur the occupants to immediately leave the building, call the fire department, or take other appropriate action to ensure life safety. Alarm signals must sound within 10 seconds of a manual or automatic initiation device activation such as a manual fire alarm box, a fire detector, or a water flow or pressure switch. In many buildings, horns, bells, or speakers are used to sound a general alarm throughout a facility. However, in other situations, an alarm may sound on only a few floors of a building or at a specific location within the building where fire alarm and other critical system monitoring takes place. When an alarm signal sounds, the level of response by occupants should be immediate and urgent. Depending on the fire alarm system, this signal either will automatically be transmitted offsite so the appropriate action can be undertaken by the receiving party or might require that a person make contact with the fire department to respond.

Supervisory Signals

The **supervisory signal** sounds when there is a change in the normal ready status of other fire protection systems or devices that are connected to or integrated with the fire alarm control panel. The typical supervisory signal sounds a constant tone, beep, or buzz usually accompanied by a visible indication (lamp, LED, or text information) on the fire alarm control panel and, if installed, the annunciator. In many buildings, the fire alarm control panel electrically monitors sprinkler system control valves; dry pipe sprinkler system air pressure; fire pump status; air temperature of a sprinkler system valve room; water temperature, level, and pressure in a water storage tank; and, in some configurations, duct smoke detector operation. For example, a change in the normal status of a sprinkler system control valve could indicate someone closed a valve, thus cutting off the water supply to the sprinkler system. This act may have been accidental, malicious, or necessary for service or maintenance activities. By electronically supervising the valve, those responsible can initiate an immediate response and investigation to determine the nature of the incident. This signal should not generate a fire department response and should be handled by building engineering, maintenance, or security staff. Supervisory signals take precedence over the trouble signal discussed in the next section.

Trouble Signals

A third type of fire alarm signal generated by a fire alarm control panel is the **trouble signal**. It sounds when there is a problem with the system's integrity, such as a power or component failure, device removal, communication fault or failure, ground fault, or break in the system wiring. It is common for the trouble signal to use the same audible signal and visible indicator as the supervisory signal to notify that there is a condition requiring attention. System problems that generate a trouble signal should be investigated and resolved as soon as practical by building maintenance or engineering personnel because trouble conditions may prevent initiation or reception of alarm signals. Many times, a trouble signal is acknowledged and forgotten, but newer fire alarm systems must sound the trouble signal every 24 hours until the problem is resolved. As with the supervisory signal, a trouble signal is not an alarm signal, and fire department response should not be necessary. However, any trouble signal should be investigated in a timely manner to determine the nature of the signal.

Initiating Devices

An **initiating device** interfaces with the fire alarm control panel to provide manual or automatic means of activating fire alarm and supervisory signals. Manual activation requires a person to operate the initiating device. Automatic activation occurs when the products of combustion or an event associated with a fire automatically activates the initiating device. There are

TIP

Most fire alarm control panels use the same constant tone, beep, or buzz accompanied by an indicating light to identify supervisory and trouble conditions. Although supervisory and trouble signals do not require the same level of response as a fire alarm signal, building engineering, maintenance, or security personnel should promptly investigate trouble or supervisory conditions.

a number of different operating principles for automatic activation, including thermal sensitivity, aspirating, detection of products of combustion or radiant energy, movement of water, changes in air pressure, and signals from automatic extinguishing systems. A discussion of manual and automatic initiating devices and their operational characteristics follows.

Manual Initiating Devices

Most initiating devices operate automatically; however, there is one exception. The **manual fire alarm box** is the only type of manual alarm initiating device; it is known by a number of different names, including *manual box*, *manual pull box*, and *manual pull station*. The manual fire alarm box requires a person to pull a handle on the device to initiate an alarm. It is critical that these devices are accessible, unobstructed, visible, and consistently located so building occupants and visitors are able to recognize and use them **FIGURE 3-4**. The purpose is to provide a manual means of activating the fire alarm system at the first sign of a fire. Still, activation of a manual fire alarm box does not guarantee a fire department response, as the fire alarm systems in many older buildings are not monitored by an on- or offsite entity that would call the fire department. Therefore, in many buildings, there are cards, placards, or signs mounted above the manual fire alarm box providing instruction to notify the fire department after safely exiting the building **FIGURE 3-5**.

FIGURE 3-4 A manual fire alarm box is typically located within 5 ft of an exit door.

FIGURE 3-5 A manual fire alarm box and instructional placard.

To ensure consistency of installation, the model codes have adopted the requirements found in NFPA 72®, *National Fire Alarm and Signaling Code®*. To provide for easy reach when exiting a building, NFPA 72® requires manual fire alarm boxes to be located within 5 ft of an exit, mounted between 42 and 48 in. above the floor, located on each side of an exit opening greater than 40 ft wide, and located within every 200 ft of travel distance measured horizontally on the same floor (National Fire Protection Association 2019, *NFPA 72,* Sections 17.15.9.4, 17.15.6, 17.15.9.6, 17.15.9.5). If the travel distance exceeds 200 ft, additional boxes are required. In addition, manual fire alarm boxes should be colored red unless the environment precludes the use of the color (National Fire Protection Association 2019, *NFPA 72,* Section 17.15.9.3). In those cases, NFPA 72® suggests the use of an alternative material—such as stainless steel—that meets the requirement for the box to remain conspicuous, unobstructed, and accessible (National Fire Protection Association 2019, *NFPA 72,* Section 17.15.9.2).

In locations where manual fire alarm boxes are subjected to moist, damp, or wet environmental conditions, they must be listed or approved for the conditions as well as appropriately protected to avoid problems with corrosion, rust, electrical shorting, and grounding. For these reasons, it is common to see some type of protective cover over these devices **FIGURE 3-6**. In many instances, the cover protects the box from the weather or other conditions that may

FIGURE 3-6 A manual fire alarm box with protective cover.

potentially cause physical damage, such as in a gymnasium where activities that use sports equipment take place.

Protective covers also help to deter individuals from pulling the box to create false and malicious alarms. Many of these covers incorporate a built-in mini-horn or siren device powered by a battery. Once the cover is lifted, the mini-horn or siren sounds a local alert rather than tying into a fire alarm system. Although these covers help to deter malicious alarms, some individuals might attempt to sound a legitimate alarm and mistakenly believe that lifting the cover initiates the fire alarm system. Unfortunately, they do not realize there is also the need to pull the handle on the manual fire alarm box. Building occupants should be instructed on how the cover works to ensure proper alarm signal initiation.

Operational Characteristics

All manual fire alarm boxes operate on the same basic principle: you must pull a lever on the box to initiate an alarm. However, some boxes may have additional operational characteristics and, according to these characteristics, may fall into one or more of the following categories:

- *Noncoded.* When activated, this type of box simply initiates an alarm until it is reset.
- *Coded.* This type of box is assigned a code that sounds from an audible notification device when a mechanical or electrical driven motor turns a wheel. A person can determine which box is operating by counting the code that is sounding **FIGURE 3-7**. For example, if a box is assigned the code "415," then an audible

FIGURE 3-7 A coded manual fire alarm box.

FIGURE 3-8 A manual fire alarm box code number "415."

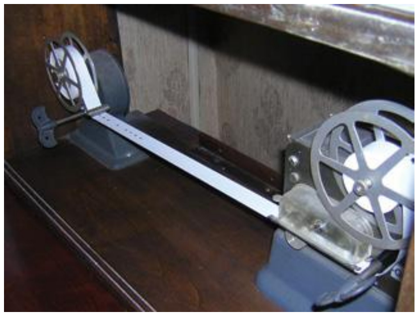

FIGURE 3-9 Upon activation of a coded manual fire alarm box, some systems have a machine that punches the code number onto a paper tape recorder so emergency responders can determine the location of the station by comparing the number to a location chart.

notification device such as a bell will ring four times, pause, ring one time, pause, ring five times, and then pause again **FIGURE 3-8**. Once the code is recognized, a person can look at the annunciator or compare the number to a code list to determine the location of the box. In addition, the system might record the event by punching the code onto a paper tape recorder, allowing responders or building personnel to verify the code or review the alarm information later **FIGURE 3-9**. To make sure the code transmits properly, coded boxes are required to repeat a code signal of not fewer than three impulses at least three times to give a person the opportunity to determine the code (National Fire Protection Association 2019, *NFPA 72,* Sections 10.11.4, 10.11.5). However, if the equipment is not maintained, dust, dirt, and dried-out lubricants may cause friction between the gears of the motor, causing the code pattern to slow down, interrupt, or stop altogether. Coded boxes are an old but reliable technology, but as systems are upgraded, fewer remain in service.

- *General alarm*. When operated, this type of box immediately initiates an alarm throughout the structure.
- *Pre-signal*. When operated, this type of box sends a signal to a location where the boxes are constantly monitored, such as a guard's desk, the main office of a school, or a nursing station. Once the signal is received, an individual can initiate an alarm; however, this initiation is typically delayed in order for the receiver to investigate the validity of the alarm.
- *Break-glass*. With this type of box, a glass rod or other breakable material must be broken before the lever can be pulled to complete the initiating action to sound the alarm **FIGURE 3-10**.
- *Non-break-glass*. This box does not have any materials that must be broken to complete the initiating action **FIGURE 3-11**.
- *Single-action*. Initiating an alarm on this type of box only requires the person to perform one action such as pulling on a lever **FIGURE 3-12**.
- *Double-action*. Initiating an alarm on this type of box requires the person to perform two actions, such as opening a protective cover and then pulling on a lever **FIGURE 3-13**.

Once a manual fire alarm box is pulled, the box requires resetting, and in almost every instance, the fire alarm system will not reset unless the box is back to normal (ready) service. Restoring a manual fire alarm box requires opening the box, usually with the use of a special key, wrench, screwdriver, or manufacturer-provided tool. Once the box is opened, some type of switch may need to be reset to the normal ready position and/or a glass or plastic rod may need to be replaced.

FIGURE 3-11 A non-break-glass-type manual fire alarm box.

FIGURE 3-10 A break-glass-type manual fire alarm box.

FIGURE 3-12 A single-action manual fire alarm box.

FIGURE 3-13 A double-action manual fire alarm box.

TIP

In order to deter malicious manual fire alarm box activation, some boxes have a tamper liquid, gel, or powder applied or incorporated that once touched, adheres to the person's skin or clothing. This deterrent is commonly used in schools and other locations that are susceptible to malicious alarms and helps to identify who activated the fire alarm box.

TIP

Restoring a manual fire alarm box requires opening the box, usually with the use of a special key, wrench, screwdriver, or manufacturer-provided tool. Once the box is opened, some type of switch may need to be reset to the normal ready position and/or a glass or plastic rod may need to be replaced.

Automatic Initiating Devices

There are a number of different types of automatic initiating devices. Some require movement of water through a pipe, the loss of air pressure from a system, or the operation of other extinguishing systems to initiate an alarm. However, many of these devices are some type of fire detector that provides early detection and warning to start notifying occupants and, in many cases, the fire department of a fire. An **automatic fire detector** is classified by the fire signature component it detects—heat, smoke, flame, or gas. Each class of detector operates differently and one may be more appropriate than another for a particular fire hazard.

In addition to the fire signature classifications, fire detectors are categorized by the class and size of the hazard they protect. Generally, there are three types of detectors: spot-type detectors, line-type detectors, and air sampling–type detectors. A **spot-type detector** covers a specific area or location. A **line-type detector** covers an area along an uninterrupted linear route. An **air sampling–type detector** pulls air from the protected area into a unit that analyzes the air by utilizing a laser or other device to check for products of combustion. Choosing to install the correct class and type of detector is critical for fast and dependable detection, prompt notification to occupants and the fire department, and a better chance of engaging, controlling, and extinguishing the fire.

Heat Detectors

Heat detectors are typically installed in areas where environmental conditions are challenging, where temperatures fluctuate, where the heat output of a fire will be high, or where the speed of fire detection is not a concern. This type of detector is very stable and not prone to false alarms, is low in cost to install and maintain, and operates by sensing predetermined fixed temperatures or sensing specified rates of temperature change. Heat detectors can be slower to detect fires than other detectors—especially smoke detectors—because they rely on the heat generated by the fire, not on the smoke that forms before sufficient heat buildup. Because they are slower to detect a fire, heat detectors are typically not considered life safety devices and, unless approved by the reviewing authority, should not replace a smoke detector. Heat detectors may substitute for smoke detectors in certain circumstances and environments where smoke detectors will not function properly because of the ambient conditions. Some heat detectors must be replaced after a fire (nonrestorable type), while others, if not damaged by the fire, can remain in service (restorable type). The type of fuel hazard, fuel configuration, and its associated rate of fire development determine which type of heat detector—spot-type or line-type, fixed-temperature, rate-of-rise, or rate compensation—should be installed.

TIP

Because they are slower to detect a fire than smoke detectors, heat detectors are not life safety devices and, unless approved by the reviewing authority, should not replace smoke detectors.

Fixed-Temperature Heat Detectors. A **fixed-temperature heat detector** operates when a sensing element within the detector reaches a predetermined temperature. Some fixed-temperature heat detectors use a fusible link sensing element that melts when the predetermined temperature is met, therefore requiring the detector or the detection element to be replaced after activation **FIGURE 3-14**. Other fixed-temperature heat detectors use bimetal sensing elements, which include different bonded metals that expand at different rates and, when exposed to increasing temperatures, cause the contacts to close, sending a signal to the fire alarm panel. Once the temperature returns to a normal level, the bimetal sensing element returns to its normal shape and, if not damaged by fire, is ready for future service.

Fusible link and bimetal element units are usually spot-type detectors, but fixed-temperature heat detectors can also be line-type detectors or detectors with electrical resistance components. Line-type heat detectors are frequently installed in challenging locations and environments because the detector, in the form of a cable, can be laid to conform to the physical conditions. Some line-type detectors are restorable but others may need to be replaced or at least have the part exposed to the fire replaced. There are different kinds of line-type heat detectors, but they all basically consist of sensing elements (e.g., conductors in a special cable) surrounded by materials that change condition when exposed to heat, causing the elements to make contact or become conductive. A newer technology uses fiber-optic cable that sends a light source through the cable. When there are changes in the light source parameters due to the temperature change, the cable distorts, causing an alarm.

Owing to a condition called **thermal lag**, some fixed-temperature heat detectors will not reach their predetermined temperature as quickly as the surrounding air will. In order to minimize the time it takes for the detector to operate when exposed to a fire, it is important to choose a temperature rating that is close—but not too close—to the normal high ambient temperature. Typically, the detector should be rated at least 20°F higher than the normal high ambient temperature. A color-coded dot or color-coded ring is typically placed on the spot-type fixed-temperature heat detector to identify its activation temperature, ranging from 100°F (no color) to 575°F (orange).

FIGURE 3-14 Once activated, the fusible link sensing element of this fixed-temperature heat detector must be replaced.

TIP

After initiating an alarm, some heat detectors require replacing, while others restore to normal ready condition if not damaged from the heat of a fire.

Rate-of-Rise Detectors. A **rate-of-rise detector** is a heat detector that uses pneumatic or electronic methods to monitor how much temperature change takes place over a fixed amount of time. When the temperature rises at a rate exceeding the fixed amount—either 5°F in 20 seconds or between 12°F and 15°F per minute, regardless of the starting temperature—a signal transmits to the fire alarm control panel. The pneumatic rate-of-rise detectors can be line- or spot-type detectors, both of which use rubber diaphragms to initiate an alarm. Changes in temperature are detected when heat expands the air in a tube that exerts pressure on the diaphragm (line type) or when the air in the diaphragm is heated (spot type). Once the diaphragm is heated, it enlarges to close electrical contacts connected to the fire alarm system. The electronic rate-of-rise detectors detect temperature change through the use of a semiconductor component (thermistor) that responds to increased temperature by increasing electrical resistance **FIGURE 3-15**.

TIP

A reset problem with a fire alarm system may stem from the need to replace a nonrestorable heat detector.

Rate-of-rise detectors typically detect temperature changes more rapidly than fixed-temperature detectors and, therefore, may not be appropriate in locations where normal ambient conditions dictate rates of temperature change that could cause false alarms. In addition, although rate-of-rise detectors are usually restorable after a fire, they may need some time to cool down before they can be reset.