FIFTH EDITION

BRANNIGAN'S BUILDING CONSTRUCTION FOR THE FIRE SERVICE

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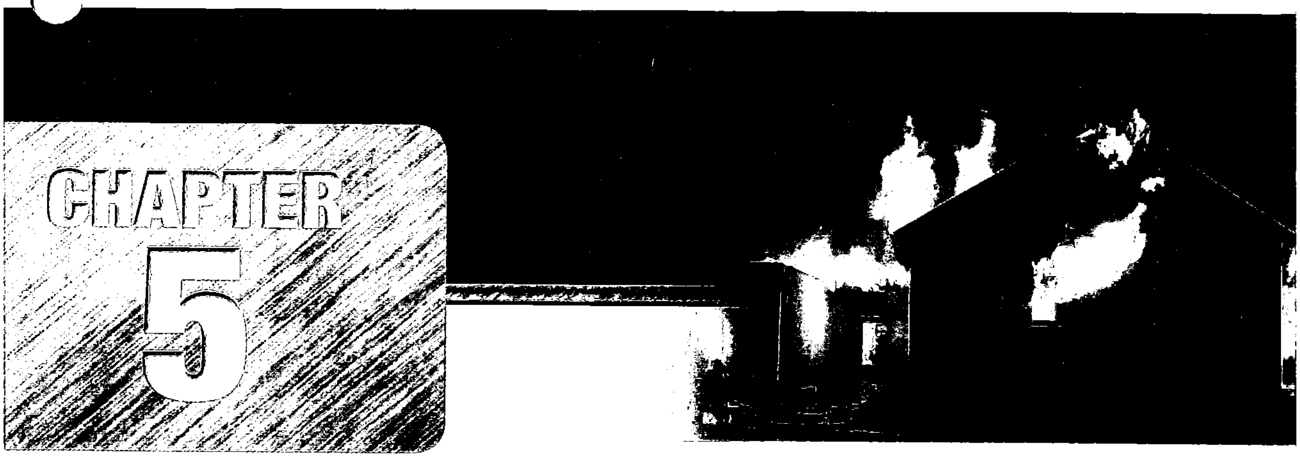
NFPA



Fire Behavior and Building Construction

OBJECTIVES

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

- Identify fundamentals of fire behavior and key fire phenomena.
- Describe the development of a compartment fire.
- Identify the ways fire is influenced by a building and its characteristics.
- List the ways buildings and their components are affected by a fire.
- Explain how specific building materials behave under fire attack.
- Describe smoke behavior and the effects it can have on the building, occupants, and fire fighters.

Case Study

Figure 5-1 The trash compactor in the basement of the Schomburg Plaza complex.

Courtesy of the USFA.

Interpreting and anticipating fire behavior are critical skills for all fire fighters. Such was the case in March 1987, when a fire broke out in the trash chute of a 35-story high-rise in the Schomburg Plaza complex in upper Manhattan (New York City). The fire started in trash jammed between the 27th and 29th floors. Arriving fire fighters were told by building personnel that the fire was in the basement compactor room (**Figure 5-1**); a line was stretched to the compactor and the fire was extinguished. Fire fighters were unaware that burning debris had actually dropped more than 25 floors and ignited the trash in the compactor.

While fire fighters were extinguishing the fire in the basement, fire was spreading vertically from the immediate area of the trash obstruction. The fire spread from the shaft via convection heat currents and radiant heat through "construction openings" in the shaft wall and by conduction into apartments on the 33rd and 34th floors through metal pipe supports and trash chute anchors. In addition, the fire spread to the top floor (the 35th floor) through autoexposure from the 34th floor.

Desperate occupants in the affected apartments made 21 calls to the fire department, in some cases reporting heavy smoke conditions, but were told the fire fighters were putting out the fire and things were under control. Dispatchers did not notify the incident commander (IC) of these calls; the IC, in fact, began returning companies, believing that the fire had been extinguished. By the time it was understood that fire had spread to the upper-floor apartments at the top of the building, seven occupants had been killed, including three who had jumped to their deaths. After the fire, valves in a sprinkler system protecting the trash chute were found to be closed.

1. Are the paths of fire spread always obvious at a fire?
2. How important is it to understand the three methods of heat transfer?
3. What role do dispatchers play during a fire?

The Basics of Fire and Fire Behavior

Although you may have learned the basics of fire and fire behavior in a fire fighter training program, it is a good idea to review this essential information. It is especially important to understand the fundamentals of fire behavior so that you will understand fire's effects on building construction and, in turn, the ways that building construction elements affect fire behavior.

Fire can be defined simply as a rapid oxidation (chemical) reaction that produces heat and visible light. To have such a reaction take place—to have a fire—four essential elements are necessary [illegible]:

- **Fuel**: a material that will sustain combustion, also known as a "reducing agent"
- **Oxidizing agent**: normally atmospheric oxygen, but may also be chemical compounds known as oxidizers that will release oxygen as they react
- **Heat**: a form of energy that is the source of ignition
- **Uninhibited chemical chain reaction**: a sustained oxidation reaction that produces sufficient excess heat to continue heating unburned fuel, making it available for combustion

An important concept in fire behavior is that of heat transfer. The effects of heat transfer can be seen in the weakening of a steel-frame structure, the rapid spread of fire across a wall surface, or the ignition of an exposure's window frames from a fire across a street. Heat transfer dictates how a fire spreads.

There are three methods of heat transfer:

- **Conduction**: the transfer of heat within an object or between objects through direct contact
- **Convection**: the transfer of heat through circulation within a medium such as a gas or a liquid [illegible]
- **Radiation**: the transfer of heat through electromagnetic waves [illegible]

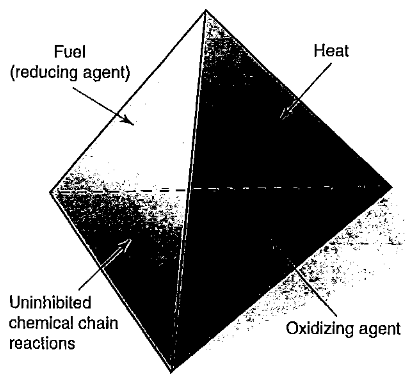


Figure 5-2 The fire tetrahedron.

Figure 5-4 The effects of radiant heat can be seen across the street from the fire as the wooden "monitor" (horizontal light shaft) on top of a mill begins to burn.

Courtesy of Glenn Corbett.

Figure 5-3 The hot gases from a fire left behind this soot and char pattern in a hallway. This effect was not caused by direct flame contact, but rather by convective heat transfer from the hot gases to the wallboard.

Courtesy of Richard Wolfson.

In more practical terms, we can see the effects of heat transfer on the fireground. A bare steel beam above a fire, immersed in the hot gases from the fire below, receives heat energy through the convection (from the hot gas "medium"). As the beam starts to heat up, heat is transferred within the beam through conduction, as well as down the length of the beam. If a combustible material such as a cardboard box is lying against the heated steel beam, it may ignite from conductive heat transfer—that is, from heat moving from one object to another in direct contact.

A large, fully involved wood-frame multiple dwelling in a row of similar structures may ignite adjacent exposures through thermal radiation. Radiation is not visible but its effects can certainly be felt on exposed skin and combustible materials. Large quantities of radiation applied to a combustible material can cause **autoignition**, a phenomenon in which a combustible material ignites spontaneously without the application of a flame or spark. (**Piloted ignition** is ignition of a heated combustible material when a flame or spark is applied.)

The term **autoexposure** has been in use for years within the fire service. You won't find it defined in most fire behavior texts, but it is still important to us. Autoexposure describes the vertical spread of fire on the exterior of a multistory building, from one floor to the floor(s) above. The flames and hot gases exiting a window pass up the side of a building, heating the window and objects in the room directly above, potentially causing them to ignite. In such a case, heat is transferred through a combination of radiation and convection.

Compartment Fires

There is a two-way relationship between building construction and fire behavior—that is, the fire is influenced by the building, and the building reacts to the effects of a fire. Typically, both of these reactions happen at the same time.

Fire scientists use the word *compartment* to describe the enclosure around a fire—an area commonly called a room. Analyzing even a moderate-sized fire in a room is a complicated process, one in which computer models and full-scale testing are helping us to better understand the complex relationship between the fire and the environment around it. We can, however, draw out some basic compartment fire principles.

If permitted to follow its natural course (no extinguishment), a fire (that is not ventilation-controlled) will often pass through these four stages:

1. Incipient: the initial stage of a fire after ignition, usually involving a single or small number of combustibles.
2. Free burning: the secondary stage of a fire in which it spreads to adjacent combustible materials (Figure 5-5).
3. **Flashover**: a transition stage in which exposed surfaces within the compartment ignite simultaneously and fire spreads throughout the compartment. Flashover results in full room involvement.
4. Smoldering/decay: a stage in which glowing combustion takes place, without flame. A fire may be forced into the smoldering stage when key components of the fire tetrahedron are in short supply, such as when the oxygen supply is limited.

A variety of terms are used to describe the various elements of a compartment fire. Some of the most important elements are the **fire plume**, which is the column of flames, **smoke**, and heated gases rising above the burning object; the **ceiling layer**, which consists of the hot, buoyant gases that collect at the very top of a room; and the **neutral plane**, which is the interface between the hot ceiling layer and the cooler air flowing into the compartment.

Studying Figure 5-5, you can see how a compartment fire sustains itself and grows. Fresh air is drawn into the fire from the doorway and is drawn into the

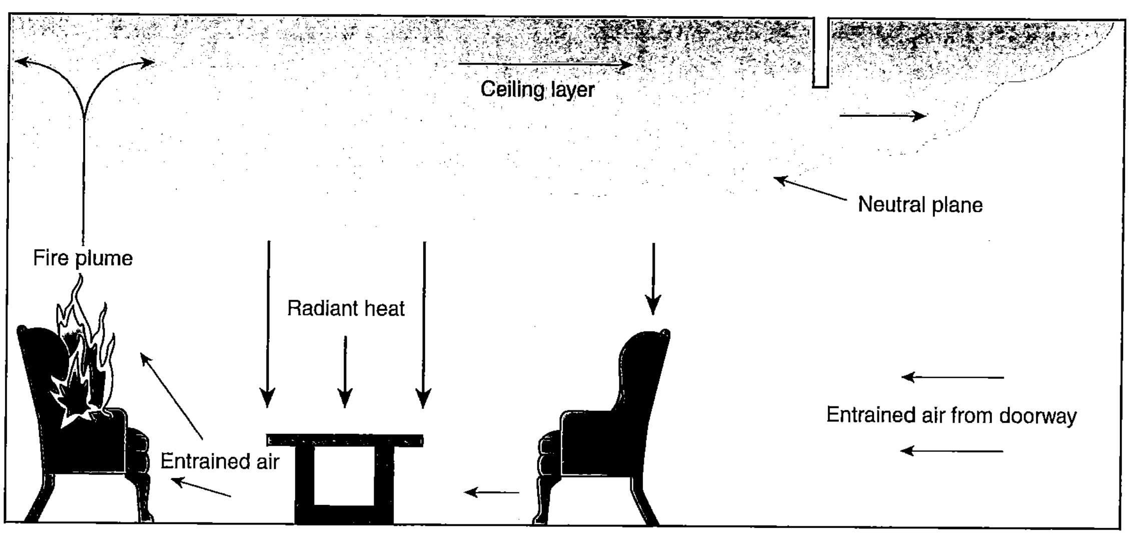


Figure 5-5 A compartment fire in the free-burning stage, prior to flashover.

fire itself; this is known as **entrainment**. The hot fire plume consisting of the hot gases and smoke travels upward to the ceiling, where it collects and then moves horizontally. Some of these gases and smoke leave the compartment through any open doors and windows.

A phenomenon known as **flameover** (also known as rollover) may be observed in the ceiling layer. In flameover, hot unburned fuel gases, having gathered in sufficient quantities at the ceiling layer, suddenly ignite. The term *rollover* describes the "rolling" motion of the flames across the bottom of the ceiling layer.

The remaining hot ceiling layer of gases and smoke in the room radiates heat to the objects below. Eventually, overwhelming radiant heat from the ceiling layer drives the room toward flashover.

A fire burning in a room will be influenced by several factors, primary among them the oxygen supply. The location and quantity of oxygen needed to feed the fire will dictate how the fire burns and grows. For example, an open door versus a closed door in a compartment will lead to a different outcome. If the oxygen supply is cut off or greatly reduced, flaming combustion will likely cease and the fire will begin smoldering.

Wind-driven fires, in which substantial winds accelerate a fire and speed up its spread, have come under recent scrutiny. If winds exceed 10–20 mph, their role in driving the fire within a building must be considered from a tactical standpoint. Current protocols call for attacking the fire from upwind and, in some cases, limiting ventilation. To deal with cases where the fire itself has broken a window on the windward side of a multistory building, the New York City Fire Department has developed a "fire blanket" to place over the opening, allowing fire fighters into that unit Figure 5-6.

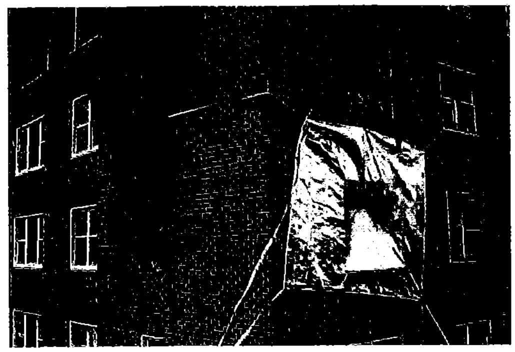


Figure 5-6 The New York City Fire Department deploys a fire blanket.

Courtesy of NIST.

In addition to the oxygen-supplying door and window openings described previously, examples of other construction factors influencing fire behavior include the following:

- Combustible interior finishes or walls, which allow for more rapid flame spread and potentially hasten flashover.
- Vertical openings such as chases and shafts and penetrations, which allow fire to spread vertically.
- The height of the fire room. Rooms with smaller heights may flash over more quickly than taller rooms (the amount of radiant heat at floor level is greater in smaller height rooms).
- The proximity of walls to each other. Narrow corridors with combustible interior finishes, for example, will tend to accelerate flame spread due to the radiant heat from the close, opposing walls.
- Heating, ventilating, and air-conditioning (HVAC) systems, whose operation may provide fresh oxygen to the fire and spread the fire.

Of course, the fire has an effect on the building and its components.as well. The most common example is the charring of wood. As the wood burns and is consumed, it loses strength. Obviously, this is important for load-bearing wood members. There is no way to determine exactly when a charred wood member under load will fail. In the case of lightweight members such as wooden trusses, the connections will likely fail first. It is best to assess the construction technique (traditional wood framing versus lightweight construction), fire severity, and fire duration to try to anticipate collapse—while understanding that this is not an exact science.

Fires can affect other materials in different ways. Steel, for example, weakens as it is heated to fire temperatures. Aluminum will melt at around 1,200°F (649°C). Some plastics will soften and melt, whereas others will char when exposed to fire. Some types of stone will crack. The bottom line: nearly all construction materials are affected negatively by fire, some more than others. Fire duration and size play significant roles in the degradation of construction materials.

Backdraft

Backdraft is the burning of heated gaseous products of combustion when oxygen is introduced into an environment whose oxygen supply has been depleted due to fire. This burning often occurs with explosive force. Backdrafts, while still fairly rare, have been on the increase, perhaps owing to increased "tightening" of buildings for purposes of energy conservation or security.

Fire Behavior, Fire Fighters, and Buildings

It is imperative to note that collapse is not the only hazard facing the fire fighter in a burning structure. Fire fighters face danger while operating inside structures—for example, being caught up in the rapid development of a fire such as in a flashover or backdraft. Concealed fire that bursts out of a hidden void and the rapid spread of fire over combustible surfaces is equally as hazardous. These hazards may account for as many fire fighter casualties as collapse does. Fire training schools conduct live training in fire-resistive structures where collapse and hidden fire hazards do not exist. Whether intended or not, the message delivered to the firefighting students is simply to "put the wet stuff on the red stuff."

It is not possible to train in the same way for collapse and hidden fire hazards. Live fire training in abandoned buildings has resulted in casualties when the training instructors did not recognize the hazards in the structure or how fire would spread. Special effort must be taken to cover these hazards in the classroom so that it is evident to the student that they are as important as putting out the visible fire.

What can be done to prevent fatalities from such conditions? The ventilation of involved structures is essential in limiting risks to fire fighters operating inside, but the ventilation process can expose fire fighters to the very dangers they are trying to reduce. ICs must recognize conditions that could cause backdraft, flashover, or flameover and could endanger fire fighters operating inside the structure.

It is also possible that these fire development phenomena may not be factored into local fire scene planning and decision making as universally as these special hazards would warrant. A careful and thorough investigation of all abnormal situations should be initiated, whether or not there are deaths and injuries. Encountering unusual heat, smoke, or burning at locations remote from the main fire area could indicate problems. Fire fighters at the fire should use care when dealing with these conditions and, following the fire, attempts should be made to understand why the conditions existed. Additional fire research may be necessary to understand how some materials burn in actual building fires, how some of these unexpected situations occurred, and how fire command and attack procedures might be better designed to reduce this risk.

Fire Growth and Spread

Fire growth and spread are greatly influenced by building construction. Whether or not a compartment goes to flashover, for example, is greatly influenced by the materials lining the walls and ceilings of the space. What follows is a description of these hazards and some of the fire protection methods employed to deal with them.

Flame spread—or the more accurate description, fire growth—is a particularly hazardous fire phenomenon. It was not recognized as such three generations ago. Unfortunately, today fire growth is still often regarded as a problem for fire prevention staff only, particularly where there is a lack of communication between fire prevention and fire suppression personnel. On November 28, 1942, rapid fire growth was responsible for 492 deaths in the Cocoanut Grove nightclub fire in Boston. At the time, flammable decorations were blamed for the rapid spread of the fire. Inadequate exits and overcrowding were blamed for the monstrous death toll. Pictures from the fire clearly show telltale globs of burned adhesives used to glue highly **combustible acoustical tile** to the ceiling (Figure 5-7).

After other deadly fires with rapid flame spread in a soldier's hostel in Newfoundland and in Mercy Hospital in Iowa, fire officials in the late 1940s began to understand that there was a problem with some building materials. Despite this linkage, early publications on the hazards of certain building materials were often criticized. Today, rapid fire growth is still imperfectly understood, even by some fire suppression forces. In 1982, two Boulder, Colorado, fire fighters died in a training fire in a building lined with combustible fiberboard.

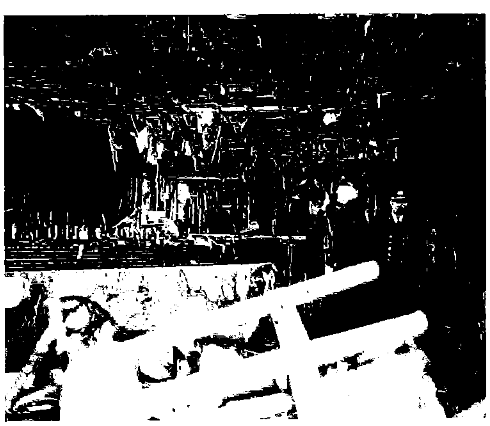


Figure 5-7 The round telltale globs of acoustical tile adhesive at the Cocoanut Grove nightclub fire.
Courtesy of the NFPA.

Examples of Fire Growth and Spread

Serious losses due to rapid fire growth have occurred across the United States. In Los Angeles, California, in 1982, fire claimed the lives of 24 occupants of the Dorothy Mae Apartments. A key factor was flame spread over plywood in the exit hall. In a 1984 Beverly, Massachusetts, fire, 15 people died in the Elliott Chambers Boarding House. Plywood paneling had been used for the interior finish of this structure. Even an activated fire detection system was inadequate in the face of the fast-spreading fire in this incident.

Combustible tile ceilings are often suspended below the floor above, creating a void in which explosive carbon monoxide (CO) gas can be generated and stored. When this gas ignites, there is often an extremely violent explosion. Three of the following five fires illustrate this phenomenon.

A magazine article described a fire in which a fire fighter and three civilians lost their lives in a flashover in a fire-resistive building. There was no mention in the article of what flashed over. A call to the article's author revealed that the fire-resistive building had been "improved" with a suspended combustible-tile ceiling, concealing a void from which the fire could burst out.

In Silver Spring, Maryland, in 1977, a fire broke out in a one-story row of stores. The ceiling was made of suspended combustible tile, which created a combustible void above the tile. The store was well ventilated, and the front windows were out. The surface fire on the tile was extinguished with a big line, but the tile continued to burn within the material and on the back side. Suddenly a huge amount of black smoke under pressure appeared—a signal that a backdraft was imminent. Fortunately the fire fighters were only knocked down and did not suffer serious injury.

Some years ago, several Orlando, Florida, fire fighters escaped from a store with their bunker coats afire. Fire had burst out of the void above a combustible tile ceiling.

Carpeting served to rapidly spread the fire in the Pioneer Hotel in Tucson, Arizona, where 28 people died in 1979. Carpeting also spread the fire in the Harmer House Nursing Home in Marietta, Ohio, where 32 individuals died in 1970. Combustible interior finish has been a factor in other fires leading to fatalities in structures where disabled or elderly people have resided.

Building or Contents Hazard?

Flame spread, or rapid fire growth, can be a problem caused by both the building itself and its contents. The fire growth building problem can be differentiated based on its location:

- Hidden
- Exposed

The fire growth contents problem can result from any of the following elements:

- Furnishings
- Interior finish, including decorations
- Mercantile stock

These categorizations are not meant to be absolute. As is the case with much of this text, it is impossible to make absolute distinctions regarding many factors in building construction. The same material may be, at different times, a hidden building element, an exposed building element, furniture, or merchandise contents in a commercial building. This can be very frustrating to those who want everything to be black or white. Unfortunately, these distinctions are often unclear.

In addition to fire growth, high flame-spread materials may contribute heavily to the fire load and to the generation of smoke and toxic products. These are additional threats to the life safety of both occupants and fire fighters.

The threats posed by particular materials used in building interiors can also be confusing. It is not wise to make any assumptions about them; instead, specific knowledge is needed. For instance, imitation brick observed in one building materials display was made of vermiculite, a noncombustible mineral material. Imitation stone in the adjacent display was made of glass fiber–reinforced polyester resin plastic; the glass fibers are noncombustible, but the plastic is combustible.

Hidden Building Elements

A wide variety of materials and hidden building elements make major contributions to rapid fire growth. The paper vapor seal on batt-type glass fiber insulation leads to a phenomenal rate of flame spread. **Batt insulation** with paper facing laid in ceilings must be kept free of light fixtures because the heat from the fixture can ignite the paper. In one case, insulation laid on a ceiling was allowed to be in contact with the top of a light fixture. It ignited, and fire spread on the paper covering the insulation. Sprinklers operated below the ceiling, yet had no effect on the fire above the ceiling.

A supermarket with a combustible ceiling was fully sprinklered, including the cockloft. A flammable liquid fire extended to the cockloft and spread rapidly onto the paper backing on the insulated underside of the roof. Twenty sprinklers operated in the cockloft and 90 sprinklers in the store, yet the fire continued to spread. In another case, an electrical fire ignited the paper backing on insulation. The fire spread through the huge undivided roof-ceiling void, which extended over the entire building.

Glass fiber insulation with paper vapor seal was installed around an upstairs bathroom for soundproofing in one of a series of connected (and expensive) dwellings in Lake Benbrook, Texas. The piping was so well insulated from heat that it froze. A torch used to thaw the pipes set fire to the paper vapor seal on the insulation, and 10 houses lost their roofs or upper floors.

Older motels are often built with back-to-back rooms, with each room opening to the outside. A plumbing corridor is often provided between the rooms. For privacy, batt-type fiberglass is sometimes installed between the studs. The paper vapor seal on this insulation is exposed. A plumber's torch could potentially ignite the paper and flash into a fire extending the length of the corridor and through pipe channels to the corridors above.

Combustible fiberboard is commonly used as insulating sheathing on wood-frame buildings. It is also used as soundproofing. This material can support a fire hidden in the walls.

Foamed-plastic insulation is also used as sheathing, concealed in cavity walls, or glued to the interior surface of masonry wall panels. Foamed plastic applied to walls and ceilings for insulation has been involved in many disastrous fires. When such insulation is installed, it should be protected from exposure to flame by a half-inch gypsum board covering. This covering protects the insulation only against ignition from a small source, however. In a well-developed fire, as the gypsum board fails, the plastic will become involved, possibly suddenly and explosively, as the gypsum falls away.

In what may be one of the costliest fires in history, workers were foaming plastic insulation around wires to prevent cross-contamination between two sections of the Tennessee Valley Authority's Browns Ferry Nuclear Power reactor. Incredibly, workers were using a candle to check for air leaks. A fire started in the foamed plastic and spread over the wiring. The actual cost of wire burned was about $50,000. The overall financial loss to the taxpayers was estimated at $300,000 per day for the year and a half the reactor was out of service.

Foamed plastic may be manufactured so that its flame spread is reduced, but it still can melt. It also lacks dimensional stability. When the plastic is used structurally, this may lead to disaster.

Air-duct insulation commonly installed years ago was usually made of a hair felt with a high flame spread. In contrast, the presently used aluminum-faced foil (not aluminum-faced paper), glass fiber insulation presents little flame spread problem.

Electrical insulation may be self-extinguishing. However, the tests of this material are conducted on wire not under load. When electrical wiring is operated at or above its rated capacity, the heat can break down the insulation and flammable gases can be emitted. The McCormick Place fire in Chicago is thought to have started in the flaming insulation of an overloaded extension cord. Large groups of electrical wires can support self-sustaining ignition.

A spectacular, tremendously smoky, multiple-alarm fire occurred in the cable vault of a telephone company building in New York City in 1975. The fuel for the fire was the insulation in the cables. A number of fire fighters suffered seriously from the smoke created by this fire.

Interior Finishes

At one time, lime plaster was an almost universal finish for ceilings, although some ceilings were also made of embossed steel (tin ceilings) and wooden boards called **matchboarding**. Plaster does not contribute to a fire. In fact, lime plaster absorbs heat, thereby slowing the progress of the fire. Today, many types of interior finishes are used, not all of which retard fire spread.

There are three ways in which interior finishes may increase the fire hazard:

- They may increase fire extension by surface flame spread.
- They may generate smoke and toxic gases.
- They may add fuel to the fire, contributing to flashover.

Commonly used interior finishes include such materials as wallboard, wallpaper, lay-in ceiling tile, vinyl wall covering, and interior floor finish items, such as carpeting.

Low-Density Fiberboard

In the 1930s, **low-density fiberboard** made of wood fibers or sugar cane residue called **bagasse** came into use. Produced in 4- by 8-foot (1.2- by 2.4-m) sheets with a painted surface, fiberboard provided a cheap interior finish that could be installed quickly. Fiberboard sales grew astronomically. This material was used both for initial construction and for rehabilitation. It was substituted for wood sheathing in frame construction. It was also widely used for interior finishes in low-cost construction.

The Celotex Company manufactured many different building materials, including a low-density fiberboard. The name Celotex is widely and inaccurately used to denote fiberboard, regardless of its manufacturer.

When low-density fiberboard is used for sheathing and for soundproofing, it is concealed in walls. A common method of igniting this material is by a plumber's torch. The plumber sees only the gypsum board wall. The fire, however, enters the wall along the copper tubing and ignites the combustible fiber sheathing. Such a fire often goes undetected until it erupts violently. Fires caused by plumbers torches have ignited many buildings under construction; in November of 1990 in Ventura County, California, 350 apartment units under construction were lost in a fire reported to be caused by a plumber's propane torch. A school under construction in New England had fiberboard on wood studs covered with gypsum board. The fire extended to the metal deck roof. The damage in this noncombustible building amounted to millions of dollars.

In a Des Moines, Iowa, shopping center, sprinklers were omitted in one part of the concealed ceiling space. Combustible fiberboard formwork for the concrete roof topping had been left in place. When a fire burned the combustible fiberboard, the estimated loss was $700,000.

An apartment fire in Gainesville, Florida, also exposed the dangers of fiberboard. The walls between units were doubled with two lines of studs, with fiberboard between them. A fire in the laundry room entered the wall void and extended to the roof, then advanced laterally through the attic.

Combustible Acoustical Tile

When punched with holes, fiberboard acquires desirable acoustical properties and becomes combustible acoustical tile. Consider the situation in a building with badly deteriorated plaster ceilings. Replacing the plaster would require removing the old plaster, placing on new plaster, and then painting—three messy jobs. An alternative is for workers to come in over the weekend, nail furring strips to the ceiling and add fiberboard tile, producing a new, attractive ceiling with acoustical benefits by Monday morning. Thus, combustible ceiling tiles may be found in addition to the original ceiling, with a void in between the two, offering a space in which fire can spread. In addition, since fiberboard acoustical ceiling tiles today are no longer considered attractive, it has become common practice to install a dropped ceiling below the acoustical tiles (Figure 5-8).

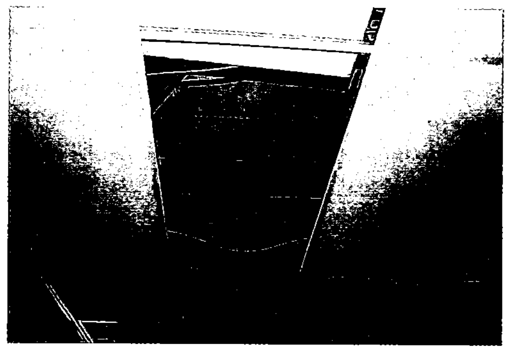


Figure 5-8 Combustible low–density fiberboard acoustical ceiling tiles above a dropped ceiling.

Courtesy of Glenn Corbett.

Industry Opposition to Regulation of Interior Finishes

Years ago, industry vigorously fought attempts at regulating fiberboard. A U.S. Department of Commerce–approved "industry standard" fire test was developed, which amounted to a fire in a thimble full of alcohol. A light flame-retardant coating enabled the fiberboard to pass this test.

In April 1949, a tragic fire occurred in St. Anthony's Hospital in Effingham, Illinois. There were 74 deaths in the fire, mostly infants in the nursery, but also nuns and nurses who would not leave them. The former *NFPA Quarterly*, in two separate issues, reported on the fire and addressed the hazards of combustible tile. Subsequently, manufacturers threatened legal action against the National Fire Protection Association (NFPA), but the association stood its ground.

A major change in industry attitude regarding fiberboard standards came about, not from reasoned explanations by fire protection experts, but as a result of a successful lawsuit against a manufacturer in the wake of the fire. Today, the flame spread characteristics of interior finishes are regulated in building codes (discussed in detail in the chapter that reviews building codes).

Other Hazards Associated with Interior Finishes

Fire hazards may exist as the result of using a wide range of materials for interior finish purposes, including tiles and fiberboard, paper, fabrics, cork, rattan, many types of wood, plastics, and carpeting.

Adhesives

In Hartford, Connecticut, the Hartford Hospital corridor ceilings were made of combustible acoustical tile glued to a gypsum board ceiling. The hazard with this arrangement had been recognized, and the tiles painted with a flame-retardant coating. In 1961, a fire developed in a soiled linen chute, rolled out, and attacked the ceiling; the fire then roared down the corridor. Ultimately, 16 patients died in the incident. Samples of the tile were tested and showed a reduced flame spread not sufficient to support as intense a fire as was experienced. The puzzled investigators removed an entire 25-foot (7.6 m) section of the ceiling and sent it for testing. The flame spread proved to be very high—the difference was due to the adhesive used to attach the tile.

The Clark County, Nevada, Fire Department report on the MGM Grand Hotel fire in 1980 noted that it required 12 tons (10,886 kg) of adhesive to attach tiles to the ceiling of the casino (Figure 5-9). The flammable adhesive added a large fuel load to the fire.

Adhesives are used in a variety of applications in building construction, including the securing of roof surfaces, the on-site assembly of prefabricated modular units, and the connecting of plastic pipes.

Figure 5-9 The fire effects in the casino area of the Las Vegas MGM Grand.

High-Density Fiberboard

Fiberboard can be manufactured to very high density. Very dense fiberboard was selected for radiation shielding in the Rocky Flats Nuclear Weapons Plant in Colorado. It was regarded as fire safe because it was tested with a blow torch. This is a commonly used but inadequate test. Long continued heat from spontaneously ignited plutonium ignited the fiberboard. The resultant fire and contamination problem was extremely costly.

When punched with holes, high-density fiberboard is called pegboard. At least one manufacturer (Masonite Corporation) produces such hardboard with a very low flame spread rating.

Paper

Some years ago, the former U.S. Atomic Energy Commission (now the U.S. Nuclear Regulatory Commission) was building an extension on Strong Memorial Hospital in Rochester, New York. Craftspeople were working on the excavation. Winter was approaching, so a temporary snow roof was erected to permit work to go on during the winter. The least expensive material available was selected for waterproofing. It proved to be a hemp-reinforced bituminous-impregnated paper of the type used to protect finished lumber—a material that has a very high flame spread rating. A stove for burning wood scraps was placed in one corner of the snow roof, creating a serious potential for sending a sheet of fire up the face of a functioning hospital. Fortunately, the situation was soon corrected.

Fabrics

The 1944 circus fire in Hartford, Connecticut, in which 168 lives were lost, was fueled by flames spreading rapidly on the gasoline- and paraffin-impregnated canvas that served as the "Big Top" tent (Figure 5-10). Panicked audience members found it difficult to escape because some exits were blocked by circus equipment. The caged runway for the wild animal show that was erected across the main exit was supposed to be up for only 10 minutes. Remember this disaster when you are asked to overlook the "temporary" blocking of exits.

In another example of a potential fabric hazard, Frank Brannigan was giving a slide-illustrated seminar on combustible decorations in the Northeast. After the seminar, attendees went to a popular local restaurant. The ceiling was draped in burlap. The fire marshal commented that there should be no problem because the place was sprinklered. He had no idea that fire could race over the burlap much faster than the sprinklers could operate. It is hard to imagine a greater panic-producing situation than fire falling from the ceiling on people, literally igniting hair and clothing.

Figure 5-10 The Hartford circus fire of 1944.

Cork

A California seafood restaurant has a ceiling decorated with cork floats. It also is sprinklered. The possibility of flames spreading faster than sprinklers can operate is often unevaluated. Cork paneling in an office was a key factor in a five-alarm fire in the Empire State Building.

Rattan

In a south Florida city, a two-story, brick and wood-joisted building had been rehabilitated into a boutique. The ceiling was of rattan. On a visit a few years later, the building was found in ruins. The fire had started on the second floor. In the words of one witness, "It spread so fast it must have been arson!" An equal possibility was that the rattan ceiling itself accelerated the flame spread.

Wood

Wood surfaces are very popular and common. Flame spread over these surfaces deserves special attention.

The unexposed side of plywood or any wood paneling can burn unobserved and protected from fire department streams. For this reason, it is not sufficient to correct such a situation by simply applying a flame-retardant surface treatment to the exposed surface. Although the standard for installation of sprinklers allows for the omission of sprinklers in concealed void spaces with such combustible surfaces in "fully" sprinklered buildings, such treatments are no substitute for exposed plywood surfaces in rooms and other open areas.

When Boston's new John Hancock Building suffered massive losses of glass window panels in the 1970s, plywood was a temporary substitute—so much of it was used that the building was known as the "plywood palace." At some point, the vertical flame spread hazard was recognized and flame-resistant plywood was used for any further closures.

Plastics

Some materials are easily recognizable. Others are disguised, such as plastic imitation wood sheathing and beams and imitation glass mirrors. **Rigid-foamed polyurethane** has been used for interior finish in many houses. In at least one fatal house fire, the material's ignition propensity and flame spread was a contributing factor. A 1971 fire in a French nightclub, in which 144 persons died, was fueled by foamed plastic used as interior finish.

Forty-nine teenagers died in a fire in the 1981 Stardust disco in Dublin, Ireland. When the Irish government convened a Tribunal of Inquiry to determine the circumstances, it discovered that the ceiling was of mineral tile and, therefore, was not a factor in flame spread. The built-in banquettes and the wall covering, however, were made of plastic. An expensive, unprecedented re-creation of the fire, commissioned by the Irish government, at the British Fire Research Station showed how a small fire in a foamed plastic seat could spread almost explosively, due to the nearby wall covering.

The Irish Tribunal of Inquiry unfortunately has no U.S. counterpart. It is a judicial body with technical expertise, which has subpoena powers and wide authority. Too often in the United States, all the facts of disasters are never revealed due to sealed settlements of civil lawsuits and the narrow scope of criminal investigations.

An interesting feature of Expo '67 in Montréal, Canada, was the United States Pavilion—a geodesic dome covered in clear plastic (Figure 5-11). One architectural writer marveled at this beautiful, lightweight futuristic building. After the building was turned over to the City of Montréal, a worker accidentally set fire to the plastic with a cutting torch. The clear plastic skin—the equivalent of solidified gasoline—was destroyed in 10 minutes.

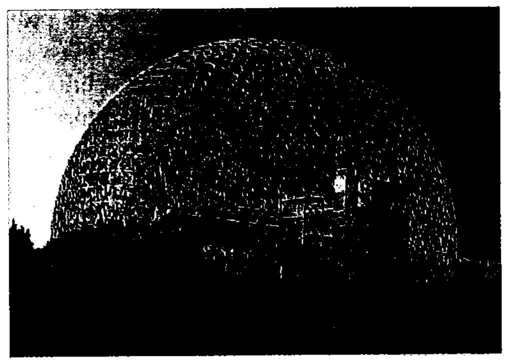


Figure 5-11 The United States Pavilion at Expo '67.

Clear plastic has many inviting uses, but not all designers understand its terrible potential hazard. The plastics supplier for the Expo building was reluctant to provide the material and had impressed on U.S. officials the necessity for strong precautions. The supplier said that when the pavilion was turned over to the City of Montréal, the company wrote to the city explaining the hazard. Some materials are probably too hazardous to use, and administrative controls on their application often are unreliable.

The Isle of Man in the United Kingdom is located in the inhospitable North Atlantic. In an attempt to create a Mediterranean-type resort, a huge entertainment complex called Summerland was built. A major portion of the walls and roof consisted of acrylic plastic, and another large portion was made of asphalt-coated steel, often called **Robertson protected metal**. The interior paneling was of pressed fiberboard. This arrangement created a combustible wall void and set the stage for disaster. In 1973, the potential threat became a reality, when a glass fiber-reinforced plastic stand caught fire outside the building. The fire extended to the asphalt-coated steel, then to the plastic. Fifty people died in the fire.

Even when the problem of combustibility is understood, other fire problems that are possible with structures incorporating large amounts of lightweight plastics are not apparent, even to architects. The retired dean of architecture at Columbia University once described a proposed pressurized membrane structure that would cover a complex of four to six government office buildings. The structure would encompass 400,000 square feet (37,161 m²). The purpose was to provide an ideal year-round environment independent of outside atmospheric conditions. There was no mention of the deadly atmosphere that would be created within the structure by the release of the toxic combustion products locked within the contents inside the environmental envelope. These toxic products could be released with a single match.

The loss of six fire fighters at the Worcester Cold Storage warehouse in Massachusetts in 1999 was, in part, due to the rapid spread of fire across the exterior surfaces of the building (Figure 5-12). The heavy timber structure—actually two connected buildings—was built in 1905 and 1912. The building had 18-inch-thick (457 mm) brick walls that were covered with successive layers of 6–18 inches (152–457 mm) of asphalt-impregnated cork (bottom layer), 4 inches (102 mm) of polystyrene or foam glass, and a thin layer of glassboard (the top layer). Additionally, maze-like conditions and limited numbers of openings were primary factors leading to the loss of the trapped fire fighters who had been looking for a homeless couple.

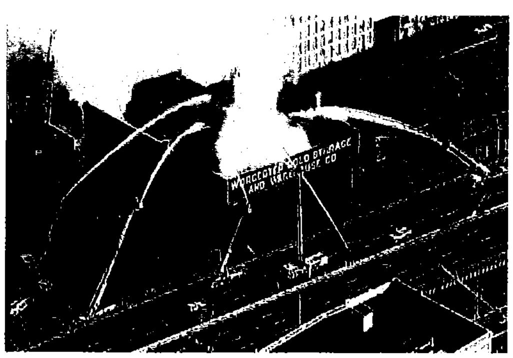


Figure 5-12 The Worcester Cold Storage building fire.
© Paul Connors/AP Photos.

Carpeting

The use of carpeting has changed. It is now also used on walls and ceilings—not just on floors. It is not always evident to designers or even to fire officials that the location where a material is installed may increase the rate at which a fire can grow. A spectacular 1980 fire in the Las Vegas Hilton Hotel spread from floor to floor outside the building because of flammable carpeting on the walls and ceilings of the elevator lobbies. The fire grew into one terrifying fire front extending many stories in height and claimed eight lives.

It has become commonplace for day care centers to use carpeting on the walls. This practice is very dangerous and must be corrected. Unless the carpeting has achieved the appropriate interior finish fire rating, it must be removed.

Void Spaces

Suspended ceilings of combustible tile form void spaces in which fire can burn undetected until it bursts out furiously. In a 1956 fire, 11 people lost their lives in Anne Arundel County, Maryland, when fire involved the attic above a combustible ceiling in an amusement hall. The raging fire overhead did not appear to be serious.

Three fire fighters lost their lives in a furniture store fire whose spread was aided by the presence of combustible voids. Heavy smoke was reported from one mile away, yet only light smoke was reported from close in at the incident. Close-in positions are not always the best place to see the situation, particularly for a multistory structure.

Fourteen people died in a fire-resistive hotel fire. The third floor, where the fire started, was the only floor paneled in wood. It also had a dropped ceiling, probably made with combustible tile.

Branniganism

Beware of "light smoke showing." Too often, it is just the tip of the fire iceberg.

Remodeled Ceiling Hazards

A most serious hazard is often created when a building is remodeled. Codes require the installation of a new ceiling that meets flame spread requirements—but they do not require the removal of the old ceiling. When the new fire-rated ceiling is installed below the old ceiling, the dangerous combustible ceiling is left above (Figure 5-13). Fire can burst down out of that void. Two fire fighters died in Wyoming, Michigan, when fire burst out of the ceiling. Even then, the city did not amend the fire code to prohibit this type of remodeling.

In the Roosevelt Hotel fire in Jacksonville, Florida, in 1963, a number of people died far above the fire floor. The fire was in an old combustible ceiling that had been left in when the new ceiling was installed. The smoke moved through old air ducts and reached areas not affected by the fire itself.

Figure 5-13 Fire can spread quickly above this tin ceiling.
Courtesy of the estate of Francis L. Brannigan.

In December 1989 in Johnson City, Tennessee, 16 people died in the John Sevier Center, a fire-resistive unsprinklered high-rise housing elderly citizens. A prime factor in the loss of life was an old combustible tile ceiling glued up to the concrete overhead and left in place when the new suspended grid ceiling was installed. National Institute of Standards and Technology (NIST) researchers noted that CO generation in such a void could be as much as 50 times what is normally generated.

Aircraft Interiors

There have been a number of aircraft tragedies where victims survived the crash but died in the resultant fire. In some cases, the fuel for the fire consisted of the plane's plastic seats and other interior fittings. Effective August 1990, new aircraft have had to meet stricter Federal Aviation Administration (FAA) standards for fire and heat resistance.

Acoustical Treatment

Acoustical or soundproofing treatment is another potential source of trouble. Many acoustical installations have been made without consideration of the flame spread consequences of materials used. The polyurethane foam used in the Station nightclub in West Warwick, Rhode Island, was used for acoustical purposes.

Open-Plan Offices

Flame spread restrictions in codes are typically strictest for corridors and less strict for rooms off these corridors. This has created a potential problem in the modern open-plan office (Figure 5-14). Where do the corridors begin and end? One fire department solved this dilemma quite simply: if there is no wall, there is no room; it is all a corridor. The strict interpretation of corridors includes the provision that they

Figure 5-14 An "open-plan" office.

enclosed, with rated walls and doors. Considering the devastating demonstration of the open office flame spread potential shown in the First Interstate fire in Los Angeles in 1988, the need for corridors to provide both a protected means of egress and a means of compartmentation should be reexamined by code-writing groups.

One little known observation resulting from computer fire simulations of the World Trade Center attacks in 2001 revealed that ceiling temperatures within a corner conference room with full height partitions were substantially lower than the surrounding open office area.

This open office–corridor mindset is prevalent throughout both industry and civilian settings. A proactive fire prevention education program can help to educate the public about these typically unrecognized hazards. The value of sprinklers in regard to flame spread and rapidly changing fire involvement should be stressed.

Alterations

Fire departments should be aware of any building alterations planned in their jurisdictions and ensure all pertinent codes are obeyed. The authors have observed a number of instances in which interior finish materials that would not have been permitted under the code during original construction were installed after occupancy. Needless to say, this may be the case in numerous buildings.

A chain of steakhouses decided to change the interior decor of the restaurants to have a rough, plastered look. Combustible paneling resembling plaster was used. It was applied without consulting local code officials. When questions about this material's fire resistance was raised, the management provided certification from the manufacturer stating that the material met local (not-too-rigorous) flame spread standards.

Decorations and Contents

Present-day decorations and building contents present major fire hazards. At one time, a popular decoration that provided a real flame spread or rapid fire growth problem was the Christmas tree. Although there are still tragedies during Christmas season, such as the loss of multiple lives at a San Francisco yacht club a few years ago, the incidence of such fires has been reduced. Regardless of any precautions taken, the number of decorations in places of assembly should be strictly limited to reduce the potential volume of fuel available for a fire.

The San Antonio fire marshal was involved in the removal of several real–cut Christmas trees from hospitals, hotel atria, and art museums. The trees were taken out of the buildings despite a newspaper editorial cartoon showing the "Grinch" with fire marshal emblazoned on his costume dragging out a decorated tree.

Decorations, usually hanging overhead and/or on the walls, and contents such as furniture or stock-in-trade are very difficult to control from a fire prevention perspective. There are few applicable regulations. These regulations, where they do exist, are difficult to write in the manner required by law and are difficult to enforce. Decorations often represent a serious problem because the hazard goes unrecognized even by people who consider themselves fire conscious.

One of history's most serious fires occurred in 1859 in a cathedral in South America. The overhead was decorated with fabric to resemble clouds. When a fire broke out, the fabric accelerated the flame spread, and about 2,000 people were reported to have died.

Closer to home are the fatal fires that have occurred when well-meaning adults create a Halloween haunted house. Often cotton sheeting is used, which has a high flame spread, in proximity to light bulbs (a 100-watt bulb can ignite cotton) or candles. One man lost his life while assembling a haunted house in a school in Virginia. The disaster would probably have been much worse had it occurred when the children were in the house. The presence of the old combustible tile ceiling above the later installed noncombustible ceiling was also a significant factor in the spread of this fire.

A 1984 fire in the Six Flags Haunted Castle in New Jersey, in which eight people died, was reported to have been caused by a visitor touching a lighter to a polyurethane surface. The NFPA report on this fire should be required reading. The extreme hazard of foamed polyurethane often goes unrecognized, yet samples of this foam ignited after a one-second application of flame from a butane lighter. The model fire code regulations that were created following this haunted castle fire have addressed this problem.

Students in a fire-resistive girls' dormitory at Providence College, in Rhode Island, had a contest with cash prizes offered for attractive Christmas decorations. Evergreen trees, made of paper and cotton applied with masking tape, provided continuous fuel along the length of the dormitory corridor. Even fire alarm boxes were covered over. Individual rooms were similarly decorated. Ten students died when a room fire extended through the hall. Dead-end corridors, permitted under the 1938 code, were a serious contributing factor to the severity of the fire. Additional stairways have since been provided.

A water treatment plant under construction had a great deal of glass fiber–reinforced plastic installed for various purposes. There appeared to be little fire hazard; the insurance was cut to the bone. After a fire occurred in the unfinished building, the contractor was paid only a fraction of the loss because he was underinsured. Because of the "glass" in the name, many mistakenly consider this type of plastic to be noncombustible—but it is not.

The Consumer Product Safety Commission created a huge acrylic plastic lobby display to show what the agency was doing for public safety. This pile of "solidified gasoline" was located between the employees' offices and the exits. A young attorney, schooled in fire protection, protested, and it was removed.

A Texas museum was very proud of a walk-through exhibit—a room full of rodeo figures. The larger-than-life-size figures were made of papier-mâché. Visitors in the museum walked on pieces of foamed polyurethane covered in burlap. A potential exit was blocked by bales of hay. Neither the creators of the exhibit nor the visitors had any concept of the hazard. A dropped match or a cigarette lighter could have created a tragic inferno.

A serious 1970 fire occurred in the then Smithsonian Institution National Museum of History and Technology. The heat produced in the fire was unparalleled in the experience of many fire fighters. The source of the heat was not understood until it was learned that huge sheets of clear plastic had hung from the overhead as part of the exhibit. The sheets had been completely consumed by the fire.

Today's Fire Loads

Fire loads and rates of heat release in current homes, stores, and offices are much greater than they were when most of the fire codes were first written. In addition, a further hazard has arisen: the nature of furniture and contents has changed. Solid and foamed plastics have replaced much wood, cotton, wool, and other materials. The hazard presented by these plastics is often unrecognized. Heat release rates—a critical measurement of fire energy output—are covered in detail in the chapter that reviews concepts of construction.

First Interstate Bank Fire

In the First Interstate Bank fire, the floor of origin had wide-open spaces crammed with computers and related equipment. Rapid fire spread over the plastic cabinets and wiring insulation produced a quickly raging fire that was reported from blocks away, while building security staff were busy resetting smoke detectors. The fire growth was thoroughly analyzed by the Fire Research Division of NIST (formerly the National Bureau of Standards [NBS]). This NIST report should be copied and discussed with the management of similar occupancies. It appears that many are still unaware of the hazard of fire loads, while others are fearful of sprinklers, and still others believe that there is plenty of time to deal with a fire.

Hotel Remodeling

pile of plastic furniture was stored temporarily in public area of the Dupont Plaza Hotel in San Juan, Puerto Rico. In December 1986, a group of disgruntled employees set fire to it. The fire grew to enormous size almost instantly and resulted in the loss of 97 lives. According to reports, claims settlements from deaths and injuries from this fire have reached $200 million.

Hotels are remodeled regularly. Mattresses and furniture often are removed from rooms and stored in hallways, where they represent a tempting target for arsonists. When carpeting piled in the hallway was ignited in a Fort Worth, Texas, Ramada Inn in 1983, five people died.

Regulations

On a national basis, little has been done to control the hazard of furnishings in buildings. However, the State of California has done a great deal, as has the City of Boston. For its own considerable holdings, the Port Authority of New York and New Jersey has laid down fire load requirements. This action was sparked by a devastating fire in a terminal at John F. Kennedy Airport, which was fueled by plastic seats. Recently developed New York State requirements, however, are concerned with toxicity, not flammability.

Certification of Interior Designers

New York State enacted legislation providing for the certification of interior designers that elevates this vocation to a new level of legitimacy. The New York law does not provide for "grandfathering." Candidates must take two examinations—one on interior design itself, and the other on building codes and fire safety. It would be useful if architecture and interior design writers could be persuaded to take the same instruction.

Residential Fire Tests

In 1980, the NBS conducted fire tests on the contents of typical residential basement recreation rooms. The word "basement" easily could be dropped from this description as immaterial. The room could be a living room or motel room, a fire station recreation room, a doctor's office, a reception area, or an elevator lobby in a hotel. The full report of these tests is a goldmine of information. Do not be deterred by the technical nature of the writing—study it.

The information concerning Test No. 14 is very revealing. The test room was 3.3 by 4.9 meters in size (10.7 by 15.9 feet). The furniture consisted of a sofa, an upholstered love seat, an ottoman, two end tables, a coffee table, and two bookcases. The carpet was ottoman pile with foam rubber backing. The walls were plywood. The ceiling tiles were wood fiber, with a 200-flame spread rating. The fire was started by matches in about a pound of newspaper on the couch. In fewer than 4 minutes, heavy flame was pouring out of the full height of the doorway. Six minutes after ignition, the average gas temperature was reported as 700°C or about 1,300°F.

Available Films

Unfortunately, there are no films or tapes generally available of the NBS tests. However, some years ago, the NFPA produced two movies, *Fire: Countdown to Disaster* and *Fire Power*, which give graphic demonstrations of how fast fire grows in today's interior environments. Although dated, they still provide a unique glimpse of the power of fire for the uninitiated. In *Fire: Countdown to Disaster*, a sparsely furnished bedroom develops a violent backdraft explosion in fewer than 3 minutes.

Control of Rapid Fire Growth

There are several possible approaches to control the problem of fast fire growth, including eliminating high flame spread surfaces, separating material from the source of combustion, cutting off the extension of the fire, and coating the materials.

Eliminate High Flame Spread Surfaces

Eliminating high flame spread surfaces is the path taken for U.S. merchant ships. Foreign ships may contain combustible trim and veneer. For these ships, reliance is placed on fire suppression from automatic sprinklers whose water supply might fail, particularly during an engine room fire. The rules for U.S. merchant ships severely limit the combustibility of construction materials and surface finishes. The rules for furnishings, however, apparently might not rule out combustible chairs or other contents that can provide the fuel for a huge fire.

Separate the Material from the Source of Combustion

In 1946, Frank Brannigan was investigating a major fire at a naval facility. An engineer who had been working there related that when building an office in the naval warehouse, fluorescent light fixtures were recessed into the combustible tile ceiling. He pointed out to workers at the time that a defective ballast in fluorescent fixtures can reach temperatures of 1,500°F (816°C). His advice to avoid contact with the ceiling was ignored by construction workers. The engineer was happy to help Frank Brannigan locate the fixture that caused the fire.

Cut Off the Extension

A metal-working shop in Richland, Washington, had no fire problems, except one: there was a dip tank in one corner. Fumes from the dip tank rose overhead and coated the wooden roof with oil, creating a high flame spread hazard. A minor fire in the tank spread rapidly under the roof, destroying the plant and closing the business. The tank should have been isolated from the main part of the plant.

Some codes require a metal door sill separating more flammable carpeting from less flammable carpeting. For example, often the carpeting in motel rooms is a higher flame spread hazard than the carpeting in the corridors, so a metal door sill is installed to separate the two. The intent is to prevent the spread of flame from a room fire to the corridor. Frank Brannigan was told by an expert that this would be effective if the door were closed, but would have no effect if the door were open.

Coat the Material

Material can be painted with a fire-retardant coating (remember, there is no such thing as "flameproofing"). One difficulty with surface coatings applied after the hazard is discovered is that they do not protect the hidden surface of the material. Fire, in turn, can burn unimpeded in the void. As mentioned earlier, the surface treatment of the ceiling tile in the Hartford Hospital fire was defeated by the adhesive.

Fire-retardant surface coatings are effective only if applied as specified. It is difficult to get painters to refrain from spreading the material too thin because there is an economic incentive to use as little coating as possible. One fire department requires that the requisite number of can labels be turned over to the inspector. This is not a foolproof method of assurance, but it at least demonstrates the fire department's interest that the job is done right. Another method is for the owner to buy the coating material and to instruct the painter as to how many square feet of surface is to be covered by a gallon.

The architect of the U.S. Capitol is responsible for the design of a number of buildings in

Washington, D.C., in addition to the Capitol itself. All of the building materials used in the original construction or in renovations are either noncombustible or treated with intumescent paints or solutions. Even structures that are constructed outdoors, such as the stand for an inauguration, are treated with intumescent paints. Such precautions proved necessary in 1960, when an electrical fire erupted in the podium at the inauguration of John F. Kennedy. Slowed by the treatment, the fire was quickly extinguished by the D.C. Fire Marshal stationed there for just such an emergency.

Pressure-treated, fire-retardant wood is often used where a wood surface is desired and flame spread requirements must be met. Wooden materials can also be formulated to be flame resistant. One manufacturer, for instance, offers a special hardboard that has a very low flame-spread rating and no fuel contribution and smoke density. Such a board would be an excellent substitute for the common hardboard and pegboard that have high flame spread characteristics.

Plastics can be manufactured to be more flame resistant. One manufacturer of structural glass fiber–reinforced plastics has produced panels that Factory Mutual (a large industrial insurance company that does a significant amount of its own fire testing in West Gloucester, Rhode Island) will permit to be installed without sprinkler protection.

Products of Combustion

Fires generate a number of products of combustion. This section discusses what the average citizen, and some researchers, call "smoke." In fact, there should be distinctions made among smoke, particles, and fire gases. Many years ago, it was considered helpful to explain to the survivors of fire victims that they did not suffer because they suffocated before they were burned! Over the years there has been a gradual change to recognition that smoke and toxic gases are more significant as fire killers than is thermal exposure.

Smoke

Smoke often provides the first warning of most fires. It can do more damage to property than the fire or water, and it may reduce visibility to zero. Its irritating particles may cause retching and immobility, and those irritants remaining in the respiratory system also may be toxic agents for a surviving fire victim.

By definition, smoke is the generic term used to describe the airborne solid and liquid particulates and gases produced by a fire. It is the solid particulates—typically carbon—that give smoke its opaqueness. The liquid particulates include acrolein and halogen acids. Gases include a myriad of different materials, including CO, hydrogen cyanide (HCN), and carbon dioxide.

Smoke Gases

Smoke gases can cause injury or death when inhaled or, in some cases, absorbed. Some gases can paralyze or slow human ability to function or escape. CO, the most prevalent of the toxic fire gases, has this effect. (HCN is also produced in many of today's fires and is now believed to be as great a danger as CO.)

For most toxic materials, the toxic effect is a product of concentration and exposure time. Haber's rule states that any exposure in which the concentration (in parts per million [ppm]) × minutes exposed equals 33,000 is likely to be dangerous. CO is probably the most common toxic fire gas. According to the *NFPA Fire Protection Handbook*, a 10-minute exposure to 3,500 ppm of CO would be hazardous, possibly incapacitating. Higher exposures with greater concentrations are even more dangerous—12,500 ppm may be fatal after only a few breaths. The toxic levels for other materials can be quite different.

Many other fire gases (such as nitric acid and hydrochloric acid, to name only two) are toxic, and, in sufficient dosage, lethal. In 1929, the Cleveland (Ohio) Clinic, like many other hospitals, used nitrocellulose X-ray film even though safety film was available. A fire in film storage facilities

Figure 5-15 The 1929 Cleveland Clinic fire.
Courtesy of National Board of Fire Underwriters/NFPA.

sent clouds of deadly nitrous oxide gas (one breath can kill) up through the building, and 125 doctors, nurses, and patients died (Figure 5-15). Some hospitals today use nitrocellulose test tubes for blood tests. There is very likely a substantial storage of these in many supply rooms. A fire in one may tragically duplicate the Cleveland Clinic fire results.

Until the end of World War II, a nitrocellulose base film was used for commercial motion pictures (fire codes still regulate it). Fires involving this film have caused many disasters. There still are places where old, deteriorating nitrate film is stored, such as in libraries and museums, and maybe even in some hospitals.

Many other materials can generate gases in a fire that are hazardous in quite small doses. Many people, including some we might think would know better, are unaware of the hazards. A retired dean of Massachusetts Institute of Technology included nitrocellulose in a list of plastics that might be useful in construction.

Polyvinyl chloride (PVC) is a very effective electrical insulator and has made itself indispensable as a contemporary material. When it burns, however, it emits toxic gases.

Gas Flammability

CO is a flammable gas. When gases ignite in a confined area, a wide range of overpressures can result, ranging from the shattering of glass windows to the shearing of brick masonry walls. Most of the technical studies conducted on CO explosions are made in connection with the design of containers. The authors do not know of any technical investigation of what happens in a typical building fire.

By observation, fire fighters note that, in some cases, CO trapped in a void or pocket simply "lights up"—that is, the gas ignites when sufficient oxygen is available. This effect is sometimes seen as flames appearing in clouds of dark black smoke pouring from windows. This is also a sign that flashover is imminent. When flashover is imminent, fire fighters should be prepared to withdraw.

In other cases, the ignition is more violent, with sufficient energy to break glass windows. This outcome is sometimes observed by neighbors adjacent to a fire in a closed building. Newspaper reports often describe an explosion that called attention to the building. In a few cases, the gas–air mixture proves just right for maximum energy release. When this happens, brick walls may be blown down.

Any or all of these effects have been described as a backdraft. Fire fighters in the vicinity are not in a position to make detailed scientific observations, of course. The many variables involved make a complete scientific study unfeasible; instead, you must understand the subject as best you can with anecdotal information from survivors.

The shockwave of a CO detonation has blown entire buildings apart. CO is not the only gas encountered under explosive conditions, however. For example, gases from burning polyurethane exploded and caused the collapse of a wall on the sound stage of a Hollywood studio in 1974.

Gases can accumulate in any enclosed area. Research at NIST has pointed out that CO can be generated up to 50 times as much in enclosed voids as in the open. Some 47 people died in a 1990 discotheque fire in Zaragoza, Spain. In this incident, a small fire in the large void above the ceiling of the first floor produced huge quantities of CO and smoke, which poured down the stairs into the basement where the victims died, many of whom were sitting in their chairs.

This tragedy is reminiscent of the 97-fatality fire in Our Lady of Angels School in Chicago in 1958. Some fire professionals share the opinion that the fire had reached the attic overhead and blew down on the classrooms, possibly when a ceiling vent was opened to reduce the temperature. Ventilation of the building does not prevent CO explosions. The gas–air mixture can pocket in a fully or partially enclosed location.

Physical Effects of Smoke

Particulates and gases have different physical effects on people. At one time, filter masks similar to those developed for use in World War I were widely used in the fire service. These masks were dangerous. The [illegible]r in that poison gas mask removed solid parti[illegible] but allowed the odorless CO through. The fire service version contained a chemical that converted small amounts of CO to harmless carbon dioxide (CO_2), but in a number of cases the CO concentration was too high and fatalities resulted.

This same characteristic may be significant in high-rise fires. In such incidents, the smoke particles and CO moving up through the building cool off. Visible smoke often stratifies, with smoke particles becoming deposited on surfaces. In contrast, the colorless, odorless, and tasteless CO can stratify well above the fire, on floors where there is little or no smoke, heat, or air movement. Fire fighters can walk into such death clouds. In 1961, a subbasement fire in a high-rise occurred in New York City. Two fire fighters, who had left SCBA behind, died of CO poisoning on the 20th floor.

Smoke particles can plug up screens. This is a problem in prisons, where screens have been used on windows to prevent passage of contraband. In one case, smoke from a mattress fire plugged the screen and inmates died. This same plugging effect should be anticipated in any location where the outgoing air is filtered, such as where toxic materials are handled.

Smoke Damage

Water damage is often considered the most expensive by-product of fire suppression. It is mentioned in most press accounts and sometimes seems to be regarded as the sole responsibility of the fire department. To varying degrees, fire departments attempt to mitigate this damage. Some departments do extensive salvage work, while others ignore it. Ironically, there is never any mention of water damage at a total loss. In fact, smoke damage may well be the most expensive by-product of a fire, particularly where delicate equipment is involved or health-menacing contamination, such as food spoiled by the smoke, occurs.

Contaminated and Toxic Smoke

It is costly enough to clean up the dirty, oily smoke that comes from materials such as plastics, but if the smoke is contaminated with another health hazard substance, such as radioactive material or **polychlorinated biphenyl (PCB)**, the cost of cleanup can be astronomical. The relationship of health hazards to fire loss is not well understood, though the problem has been around for some time.

The fire problem of radioactive material grows out of the fact that radioactive materials emit energy that can damage living tissue; thus concerns about the safety of personnel might demand abandonment of the property until it is cleaned up. In the Rocky Flats Nuclear Weapons Plant, a fire did about $1 million in conventional damage. The cost of the total cleanup was 25 times greater.

Whether the fire fuel is radioactive or a fire in another fuel disperses the radioactive material, the results can be similar. In the Hanford, Washington, nuclear power plant, a fire spread contamination more efficiently than a nuclear accident. A nuclear experiment went critical (when a nuclear reaction becomes self-sustaining) and spread contamination around the building. It was successfully cleaned up with paper diapers, acetone, and nitric acid. The waste was then packaged to await disposal, but the nuclear cleanup experts had forgotten their chemistry. The sealed packages ignited spontaneously. The fire spread the same contaminants so effectively that it was not economically feasible to clean up the area. The nuclear power plant was closed off and years later dismantled and buried.

It is easy to control the health hazard of contamination—keep people away. Because the loss of use of a property can be very costly and cleanup can be prohibitive, it is sometimes less expensive to abandon the property.

There have been many serious contamination incidents from PCBs released from electrical transformers during fires. PCBs were used as nonflammable coolants in transformers. There are rules requiring notification of emergency responders of the presence of PCBs, but they are not infallible.

During a relatively small fire in an office building in Binghamton, New York, in 1981, a transformer cracked. PCBs that were used in the transformer coolant heated up and released toxic products into the atmosphere. It took years to clean the building, which finally reopened in 1995. Cleanup costs exceeded the value of the building. The cleanup was slow and costly because of the precautions that had to be taken to protect the workers. Fire fighters should be aware of the extremely toxic nature of PCBs and the fact that these chemicals can be released from any transformer by fire or accident or even in routine maintenance.

The telephone system is the nervous system of the community. Daily life is disrupted when phone lines are out; serious financial losses also can occur when such service is unavailable. Thus, fires in telephone company facilities are not ordinary fires. In addition, the toxicity of the smoke for fire fighters, including the by-products of burning plastic wiring insulation, is a major concern. In 1975, a massive disruption of communications resulted from a fire in a basement cable vault of New York Telephone's main switching center. On May 8, 1988, a serious fire occurred in an Illinois Bell Telephone Central Office in Hinsdale, Illinois. Much of the multimillion dollar loss was due to smoke damage. Fire fighters in both fires suffered the effects of the toxic smoke.

Many of these telephone switching facilities lack sprinkler systems. Some only have detection systems. In another fire, a $30 million loss was suffered when a fire confined to burning PVC-insulated cables and the roof above them generated smoke that corroded precision machinery.

Corrosion

Delicate equipment as well as brickwork and concrete can be damaged or destroyed by corrosive products of combustion. Plastics containing halogens such as chlorine, fluorine, bromine, or iodine form corrosive acids when combined with hydrogen and oxygen or moisture in the air.

Smoke Movement

Generally, fire gases rise due to buoyancy. We are all familiar with the fact that gravity causes things to fall down, but few of us know that gravity pulls down on the surrounding heavier, colder air, causing the lighter, heated smoke of a fire to rise upward. If the smoke is not ventilated, it will cool and remain inside the building, even after the fire is out. Even with PPV and venting in progress, there is still danger from these gases. Cellars and low, unvented areas become collection points. Use of SCBA is critical in the overhaul stage of a fire.

When elevators were first introduced into buildings, designers saw the need to surround the shaft with a cage to prevent people from falling into it. There was no recognition of the fact that the open shaft was a perfect path for the extension of fire upward.

TACTICAL CONSIDERATIONS

1. Like elevators, stairwells, and mail chutes, garbage chutes are one of the truly open shafts in high-rise buildings. The door is a 90° pull-down, self-closing door. The sprinkler is usually above the door opening to the chute. Often it is difficult to see and difficult to reach. If the piping sticks out too much, garbage falling from above can hang up on the sprinkler. There is a variety of scenarios in which the fire in the trash receptacle in the basement, or anywhere else in the chute, can spread to upper floors—vertically, then horizontally. An arsonist who understands fire behavior and sprinkler systems can shut off the main valve or sectional valves so the incendiary fire can spread. Commercially monitored systems make this harder to do without immediate detection. A more likely scenario is when large objects of trash are crammed down the shaft, which acts like a cork in the chute, and wedges the door in the open position. Smoke coming up the shaft can then spread through the wedged open door, filling the small maintenance room with smoke. If that door is open, the smoke can move directly into the hallways.

   Another scenario is when the system is shut down and drained to change a sprinkler. It is difficult for sprinkler technicians to access these sprinklers as well; the time from the previous fire, to when the sprinkler system is recharged and back in service, makes the chute vulnerable to fire.

   The bottom line is this: fire crews need to check each floor, each maintenance room, and open each trash chute door to ensure there is no vertical and horizontal spread from fire. A fire fighter should also check the CO readings using a gas detector during this top-to-bottom investigation.
2. During an actual fire, dispatchers often get calls from residents within a high-rise building reporting an alarm sounding, an odor of smoke, a fire, or all three. If the building has a supervised monitoring alarm system, this confirms that there is a fire and full response is dispatched. Typically, the dispatcher will then announce to the responding companies, "We've received numerous calls," indicating that callers are verifying a fire. Once the alarm is dispatched, additional calls into the fire alarm center are answered with, "Yes, we're on the way," or "Thanks! We've got it."
3. Though it is important not to tie up 911 lines reporting an alarm where the fire department is already on scene, dispatchers shouldn't be too quick to dismiss callers, especially in high-rise residential buildings. The dispatcher should make note of the caller's room number and relay this information to the IC. For example, if the fire was on floor 4 of a 20-story building, the dispatcher can say, "IC from dispatch, we've received calls from 808, 908, and 1,510 reporting an odor of smoke." If floors 8, 9, and 15 were already checked and reported cleared from smoke, the IC can send crews back up to the actual units to check on the caller. Not only is this good customer service, it will also put the caller at ease. From a tactical standpoint, these apartments are vertically aligned and there may be smoke extension that cannot be determined from the hallway.
4. Unfortunately, fire fighters sometimes judge the danger of smoke based on its density, interpreting light smoke as tenable smoke. Many fire fighters have suffered the effects of CO in light smoke conditions. A fire fighter who is acting "strange" or irrational is suffering the effects of CO. Another common sign is a fire fighter who is alone (without his partner) and going the wrong way—toward the fire. If a fire fighter appears disoriented and is not wearing an SCBA face piece, he needs to be immediately assisted to safety.
5. Firefighting tactics, in one form or another, are always removing one leg of the fire tetrahedron. Even complicated fire incidents are, in their simplest form, removing one leg of the fire tetrahedron. The most common extinguishing agent is water. Water absorbs heat and cools the fuel below its

ignition temperature so it's not giving off fumes. An unorthodox but effective way to use water to remove the fuel leg of the fire tetrahedron is when a magnesium fire is encountered. Magnesium is flammable metal that, when burning, reacts violently with water. Fire fighters are told never to use water on a magnesium fire. However, under certain circumstances (and understanding fire behavior), that is exactly the tactic to use. Left on its own, a large magnesium fire can take a long time to burn itself out. Fire units will have to remain out of service for the duration. Lobbing water from a safe distance using master streams will create a spectacular fire, but it will also burn the magnesium up at an accelerated rate. The faster the fuel is consumed, the faster the fire will go out. The situation is resolved and units can go back in service because the fuel leg of the fire tetrahedron was removed.

6. Heat transfer and fire spread happen through conduction, convection, and radiation. Using a thermal imager, fire fighters can quickly locate concealed fires or determine the location of the fire no matter which medium is used by the fire.
7. During vertical ventilation operations, fire fighters often forget to take a hose line up to the roof. Radiation can cause the uninvolved roof decking or the siding of an adjacent exposure building to autoignite. Hose streams have tremendous reach and can be operated from a safe position; we must keep what we're trying to save wet. If it's wet, it won't burn.
8. Thermal radiation impacting an exposure building may cause ignition of the exposure, including any combustible wall surfaces or combustibles inside the exposure near a window. Hose streams must be applied *directly on the exposure building* to remove the heat. Simply placing a stream between the buildings will not stop the radiant heat; it will pass right through.
9. Many company officers and fire service instructors still teach that fire fighters should not destroy the thermal layer (neutral plane). This has been taught for decades, but things have changed. Fire fighters have hesitated to apply water because they were taught never to destroy the thermal layer. It must be understood that with today's plastics and synthetics fuels, ceiling layer gases must be vented or cooled or they will ignite.
10. Examine the issue of the "thermal balance" and firefighting. First, you have good visibility below the neutral plane. This allows you to search for unconscious victims. Second, as soon as the nozzle opens up into the ceiling, the thermal layer is stirred and visibility is lost. Third, you create steam, which makes the room untenable for victims. Where they may have been saved, the hot, steamy environment can be deadly. This can be avoided if a sprinkler head is activated.

    Today's household fuels burn faster and at higher temperatures than the wood, cotton, and paper fuels of the past. The temperature below the neutral plane is much hotter for a victim with exposed skin, wearing household clothing. The survival profile is low. Our modern bunker gear can withstand temperatures above 220°F (104°C)—though it's still uncomfortable. Finally, thermal imagers allow us to see in zero visibility.

    Protecting the neutral plane is a plus if you can ventilate. But if you can't, or ventilation is going to be delayed, you must cool the ceiling fire gases below their ignition temperatures with water. It doesn't matter if visibility is good below the neutral plane if the room flashes over.
11. Remember, flameover or rollover may be your last warning sign before flashover.

    From a tactical point of view regarding fire behavior, this is the most important concept to understand. Remember that the fire is always looking for the path of least resistance. Learn this. Teach your fire fighters the gas laws of physics. Many tactical considerations are based on the premise. Once you understand this, it will be much easier to predict what the fire will do and where it is going—without surprises.
12. Many fire departments don't have the resources or ability to deploy a fire blanket to cover the entry point of a wind-driven fire. These blankets are heavy because they have to resist the wind without being pushed through the entry point window. There are other tactical options to consider.

    - First, trailer-mounted mobile ventilation units (MVU) are becoming more popular for ventilating big-box stores. But depending on the wind speed and the cubic feet per minute (cfm) capacity of the MVU, you might be able to overpower the wind currents and reverse the effects of a wind-driven fire. If this is not possible, there is no stopping a wind-driven fire until it meets a fire-rated barrier. Keep in mind that everything between the entry point and that barrier will be subject to a blowtorch velocity fire and the survival profile is zero. The fire load will be consumed. You cannot withstand or survive these horizontal-pressurized flames. If the fire barrier (a wall or fire door) holds, the fire will slow down as fuel is consumed or it will burn itself out.

- Another option is attacking the fire from the floor above. A Bresnan distributor nozzle (a 2 ½" appliance that can throw 260–290 gallons per minute [gpm][984–1098 Lpm]) can be inserted if a hole can be cut through the floor. Fog applicators and piercing nozzles can also be deployed, but they may not have enough gpm by themselves. Multiple appliances would have to be deployed. The water-to-steam ratio doesn't apply here because this isn't an oxygen-deficient, confined space. A Bresnan nozzle can also be lashed to an attic ladder and inserted from the floor below if there are no concrete floors. Inserting these nozzles through the walls of an adjacent room can afford a horizontal attack but these adjacent rooms may not be accessible from the hallway. If aerial ladders can reach, the adjacent rooms can be accessed through an exterior window.
- Aerial master streams can be deployed if they can reach. Everything between the wind-driven access point to the first fire barrier is a zero survival profile, so a frontal attack through the window is your only option. The fire needs to be extinguished.
- If the streams can reach, consider deploying portable monitors from the windows of adjacent buildings. This may be a last-ditch effort.
- Finally, protect the fire doors to the stairwell and write off the fire floor. Firefighting efforts will need to be concentrated on the floor above. "Flow the floor" keeping everything wet. Remove all fire load away from windows and exterior walls. Watch for smoke and fire extension through the HVAC system, elevator shafts, and other poke-through holes. There should be standing water on the floor, especially if it is carpeted.
- Another tactic that may work is attacking the fire from windows on the floor below the fire. Hose streams can be aimed up and out the window directly into the wind. The wind should push the stream back directly into the wind-driven opening and onto the fire floor.

13. Aluminum will melt at approximately 1,200°F (649°C). This is a good number to memorize since most of our ground ladders and some aerials are made of aluminum. But don't forget that aluminum also anneals when exposed to prolonged heat of 350°F (177°C) and higher—that means it starts to lose its rated strength. This is also a number worth memorizing.
14. Hidden fires are just that—hidden! That means fire fighters are not having success uncovering them. The best technology we have today is the thermal imager. Left untended, hidden fires will only get worse and emerge with increased momentum.
15. Understanding fire behavior and the fact the fire will take the path of least resistance, PPV fans can be used to help locate hidden fires. This may seem extreme, but the goal is to locate the fire so it can be extinguished.

    The fans are used to pressurize the space and accelerate the burn by introducing forced, oxygen-rich air. Have the hose lines charged and the teams ready to go with tools to open the walls or ceiling. Keep a fire fighter at the fan the entire time. As soon as fire starts to present, have the fire fighter at the fan shut it off or aim it away from the entry point. Fire fighters now know where the fire is and can dig it out.
16. When fire fighters get trapped in a room and must get out immediately, we teach them to breach the wall and perform a reduced profile, self-extrication into the next room. We need to expand on this concept and apply it to getting patrons out of a public assembly where a fire has occurred and exits are overcrowded by panicked patrons trying to escape.

    Make existing exits bigger by removing doors or tying them open. Don't use wedges because they can be kicked loose. Make windows into doors. Create doors in walls. These extra openings will draw the fire. Hose lines have to be deployed above the heads of the escaping customers. The goal is to get everyone out as soon as possible.

17. We don't ventilate only for smoke. If there was a fire and smoke conditions were light, fire fighters often settle for natural ventilation. CO is odorless and colorless. Use a PPV fan from the outside or electric fans from the inside. Use the gas monitor to ensure levels are below 35 ppm.
18. A rescue air kit (RAK) is a spare SCBA bottle, face piece, and regulator that is carried in a special bag that is specifically designed for rapid intervention emergencies when a fire fighter is trapped. The RAKs are commercially made, but some fire departments assemble their own versions. It is one of the primary pieces of equipment a rapid intervention team (RIT) carries in for fire fighter rescue. But what do we carry in for civilian search and rescue? It is not a common practice to take in a RAK for civilians, but perhaps we should start. Most fire departments train their personnel to search and rescue the victim by dragging or carrying them out of the building. Then resuscitation efforts begin. In the past, a fire fighter may have given up his face piece to the victim, but this is not a smart thing to do. If the fire fighter is overcome with smoke and the effects of CO, there will be two victims to rescue.

    RITs should be reserved for that purpose alone, but often there are other RAKs sitting unused in the compartment of another apparatus. It may be time to start equipping fire fighters assigned to search and rescue with a RAK for civilian victims.
19. Piercing nozzles are making a comeback. These nozzles are excellent for insulation fires in floors, walls, and ceilings. Insulation fires tend to smolder for hours. Digging it out is a tedious task, especially with "blown-in" insulation. Embers are difficult to find. Some fire departments use Class A foam for these situations but don't rely solely on a foam blanket. The author has experienced a situation where a stubborn (blown-in) insulation fire couldn't be extinguished. There were slight puffs of smoke coming from the insulation but no embers could be found. The decision was made to use Class A foam and apply it heavily. The fire rekindled 5 hours later and a full response was dispatched to the same location for a house fire.
20. Open the walls. Charred wood should be taken down to clean lumber unless the structural stability is in question. In that case, use Class A foam. Consider using piercing nozzles or fog applicators. Create a sprinkler system where none exists. A round nozzle throws a different spray pattern than sprinklers.
21. It is no longer unreasonable to expect that fire fighters should not suffer from smoke inhalation injuries. Unless you're trapped or in a situation where you're going to run out of air, you and your crews should be practicing air management principles. This does not mean to work in the IDLH until your bell starts ringing. Conscientious and safe fire fighters are going to exit the IDLH before their bell starts ringing. Forty-five-minute SCBA bottles provide enough time to make a difference. If things aren't getting better after one bottle, reevaluate the situation. Perhaps you are missing some clues. Make sure your fire fighters are all wearing SCBA in the hot zone.
22. In multistory structures, close-in positions for the command post don't always provide the best position to grasp the scope of the emergency. Consider sending a chief officer up into an adjacent building for an aerial perspective. Even bridges in the immediate area can provide an excellent perspective for a deputy IC to report conditions that cannot be seen from the interior or from the ground. This simple solution is not utilized nearly enough. We are programmed from day one to respond to the address and set up the command post in front of the building. Consider setting up the command post in an upper floor of an adjacent building with a better view of the fireground and leave the Operations Chief at the front of the building. If there was a fire on floor 50 of a high-rise building, it would be difficult to judge fire conditions from the street. However, if the IC went to the 50th floor of the adjacent high-rise building, more information could be gathered to make better strategic decisions.
23. Don't rule out using police or news helicopters to get a close-up aerial view. Technology is now available where video feeds from helicopters can be relayed in real time to computer monitors inside fire apparatus and command vehicles.

24. When we have to enter a below-grade, confined space for a rescue, we check the oxygen percentage before entering the space, often by lowering the gas detector on a tag line to check for CO and oxygen-deficient atmospheres. In an overhead void space, the CO levels must be determined because they can explode under the right conditions. If we had smoke conditions, we know CO was generated. Apply the same tactic, but reverse it. Try attaching a portable gas monitor to a two-pronged rubbish hook or an attic ladder for extended reach.
25. When dealing with a fire in a large space with suspended ceilings, consider requesting additional fire crews equipped with pike poles. Voids need to be checked as quickly as possible. Have a ventilation plan. Remember to bring in roof ladders and attic ladders. Stage them close by. If a suspended ceiling grid collapses on fire crews, the ladders can be shoved underneath the grid to help lift up large sections of ceiling to help free entangled fire fighters.
26. Remember, sprinkler systems do not wait to activate until all occupants are safely out of the building. They fuse at their designed temperature threshold, creating steam, destroying the thermal layer (neutral plane), and reducing visibility. If you look at a sprinkler system in any hotel room, in essence, it is actually a piercing nozzle. The plumbing is inserted through the wall the same way a piercing nozzle would punch through a wall. An activated sprinkler head is actually an indirect offensive attack.
27. If you visit an ARFF fire station at any major airport, you'll notice at least one first-line crash truck is equipped with a preplumbed piercing nozzle. We should follow their lead in ARFF tactics as it relates to attacking fires inside structures that may be difficult to access. ARFF realizes that the plane may be surrounded by flames and aircraft doors may be difficult to breach, especially if the crew and passengers are injured to where they cannot assist opening the doors from the inside of the cabin. The cabin can be quickly filling up with toxic smoke. ARFF doesn't take a defensive posture with passengers on board. The *Snozzle* is ready to deploy and rams the fuselage (with controlled precision) with the piecing nozzle and introduces a sprinkler system into the cabin. They have to stop the production of smoke and ventilate as soon as possible. Manual efforts are too slow during the initial phases of the attack. The basic strategy is this: introduce a sprinkler system into a confined space.
28. Los Angeles Fire Department (LAFD) fire fighters finally extinguished the First Interstate high-rise fire by what they called "flowing the floor." They removed the fuel load (e.g., furniture, computers, window dressings) away from the windows and exterior walls and toward the center of the room. They monitored the HVAC system and then flowed water on the floor until there were a couple of inches of standing water. If everything is wet, especially the carpeting, it won't burn. Keep exposed fuel wet.
29. Fraternities and sororities are notorious for decorating house/dormitory hallways and bedroom doors with decorations, artwork, notes, and signs. Most of them are made of paper and create an increased fire load in the hallway. Though paper products burn fairly quickly, the flames produced may be high enough to catch the carpeting or other structures on fire that would generate more heat output. The crew going up to investigate a fire alarm should always have a 2.5-gallon (9.5 L) pressurized water extinguisher. Standby crews can hook up to a hydrant and lay a precautionary hose line.
30. Toxic smoke gases are obviously a respiratory health hazard that can be fatal, but many toxins in smoke can also be absorbed through the skin. Make sure your fire fighters are wearing SCBA and proper PPE during overhaul. Limit exposed skin. In hot weather, rotate crews.
31. Many PPV fans are shut off after the smoke clears and occupants are let back into the building before CO readings are taken throughout the occupancy. In one major city, a fire occurred in a restaurant on the first floor of a 12-story building. The restaurant was closed for remodeling and the fire had a head start before fire fighters arrived. After the fire was out and visible smoke was vented from the building, occupants on floors 11 and 12 were complaining of feeling ill. The IC sent a fire crew back up to check the floors with a gas detector. Though the floors were clear from smoke, CO levels were well above 35 ppm. Without taking a CO reading, these floors appeared as though they were unaffected by the fire. CO levels need to be

checked from the top floor down to the bottom. If this is a high-rise building, the IC has to be selective but determine how high CO was able to ascend in the building.

32. Ventilation of the building does not prevent CO explosions. The gas–air mixture can accumulate in a fully or partially enclosed location. This does not mean you shouldn't ventilate; it means there may be enclosed void spaces or rooms that are shielded from the PPV airflow path. Ventilation is the only method by which fire fighters can expel CO from a building. Be systematic and thorough in your ventilation plan.
33. Smoke follows the path of least resistance. PPV is more than just removing smoke from a building. It introduces fresh air into the environment, creating a more survivable atmosphere for the victims, it cools the environment, it dilutes the products of combustion, it helps lower the temperature of fuels, it can help spread water vapor created from the hose streams, and most important, from a tactical perspective, it changes the direction of the smoke and the fire. Effective ventilation can *make the fire behave*. Remember, especially in vertical ventilation, wherever you make your hole, that's where you're bringing the fire. If you think of ventilation holes as "exit holes," it will help you make the decision on where to cut or break a window when it isn't possible to vent directly over the fire.

WRAP-UP

Chapter Summary

- Understanding fire behavior—including the effects and hazards posed by heat transfer—is critical for all fire fighters and can influence tactical decision making.
- While compartment fires are complex and dynamic, fundamental aspects of the combustion process can be identified and understood. The most important factor is often the oxygen supply—the location and quantity of oxygen needed to feed the fire will dictate how the fire burns and grows.
- Fire behavior is influenced by building construction; buildings can be negatively affected by fire in a variety of ways, including the materials lining the walls and ceilings of the space.
- Fire fighters are at great risk from rapid fire growth, especially where there is a lack of communication between fire prevention and fire suppression personnel.
- In addition to fire growth, high flame spread materials may contribute heavily to the fire load and to the generation of smoke and toxic products.
- There are several possible approaches to control the problem of fast fire growth, including eliminating high flame spread surfaces, separating material from the source of combustion, cutting off the extension of the fire, and coating the materials.
- Smoke is a generic term used to describe the collective group of solid and liquid particulates and gases.
- Smoke can affect occupants, fire fighters, and buildings in many ways, and may well be the most expensive by-product of a fire.

Key Terms

Autoexposure The vertical spread of fire on the exterior of a multistory building, from one floor to the floor(s) above, via convection and radiation.

Autoignition A phenomenon in which a combustible material ignites spontaneously without the application of a flame or spark.

Backdraft The explosive burning of heated gaseous products of combustion when oxygen is introduced into an environment whose oxygen supply has been depleted due to fire.

Bagasse Low-density fiberboard made of wood fibers or sugar cane residue.

Batt insulation Fiberglass or rock wool insulation with various thicknesses; it may or may not have a paper covering.

Ceiling layer The hot, buoyant gases that collect at the very top of a room.

Combustible acoustical tile Fiberboard in which holes have been punched.

Conduction The transfer of heat within an object or between objects through direct contact.

Convection The transfer of heat through circulation within a medium such as a gas or a liquid.

Entrainment The process of oxygen (air) being drawn into a fire.

Fire plume The column of flames, smoke, and heated gases rising above the burning object.

Flameover A situation in which unburned fuel gases, having gathered in sufficient quantities at the ceiling layer, suddenly ignite; also called rollover.

Flashover A transition stage in a fire in which exposed surfaces within the compartment ignite simultaneously and fire spreads throughout the compartment, resulting in full room involvement.

WRAP-UP

Fuel A material that will sustain combustion.

Heat A form of energy that is the source of ignition.

Low-density fiberboard Sometimes used as an interior finish, a product made of wood particles such as wood shavings and bound together with a suitable binder.

Matchboarding Ceilings made of embossed steel and wooden boards.

Neutral plane The interface between the hot ceiling layer and the cooler air flowing into the compartment.

Oxidizing agent Normally atmospheric oxygen, but may also be chemical compounds known as oxidizers that release oxygen as they react.

Piloted ignition Ignition of a heated combustible material when a flame or spark is applied.

Polychlorinated biphenyl (PCB) Toxic chemicals used as nonflammable coolants in transformers that may be released during fires.

Polyvinyl chloride (PVC) A commercially produced organic compound used in transformers and capacitors due to its electrical insulator properties and low flammability rating.

Radiation Heat transfer of heat through electromagnetic waves.

Rigid-foamed polyurethane Cellular foam plastic that is used as an interior finish.

Robertson protected metal Asphalt-coated steel.

Smoke The airborne solid and liquid particulates and gases produced by a fire.

Uninhibited chemical chain reaction A sustained oxidation reaction that produces sufficient excess heat to continue heating unburned fuel, making it available for combustion.

Case Study

Fire service leaders have said that the two main subjects fire fighters must know are fire behavior and building construction. Understanding the basics of fire behavior and how buildings react to fire will help you develop an appropriate tactical response to a given situation.

1. The four sides of the fire tetrahedron are fuel, an oxidizing agent, heat, and:

A. an inhibited chain reaction.
B. an uninhibited chain reaction.
C. smoke.
D. flashover.

2. Which of the following is *not* a method of heat transfer?

A. Conduction
B. Backdraft
C. Convection
D. Radiation

3. Fill in the blank: _______________ is a transition stage in which exposed surfaces within the compartment ignite simultaneously.

4. What is the common name for fiberboard punched with holes?

A. Batt insulation
B. Rigid foam insulation
C. Matchboard
D. Combustible acoustical tile

Challenging Question

You are a captain who has been temporarily assigned to the fire academy. You are to assist in teaching a basic fire behavior class to new recruits. Using Figure 5-16, fill in each blank to identify important components of a free-burning compartment fire, provide a brief description of each of these components, and generally describe the combustion process in this diagram.

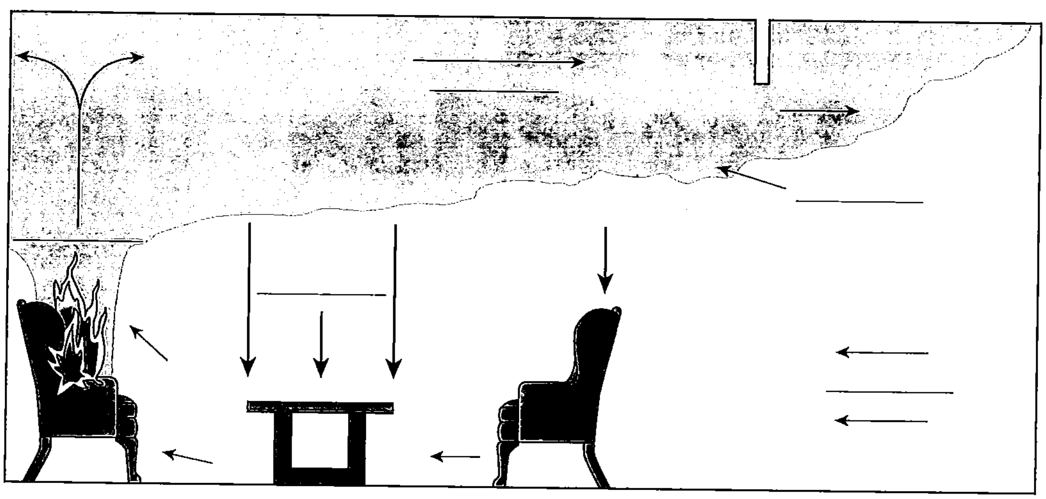
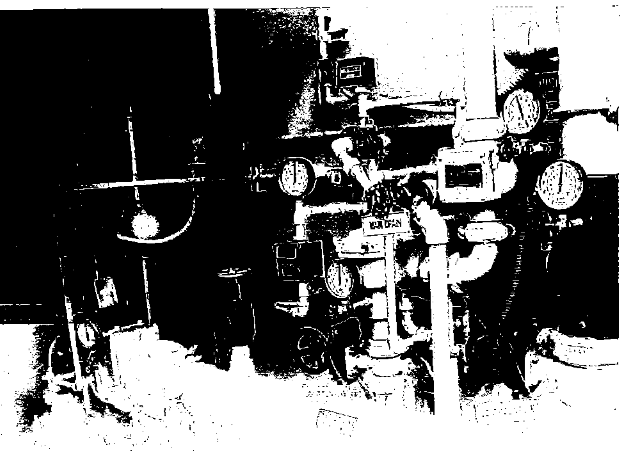


Figure 5-16

CHAPTER 6



Features of Fire Protection

OBJECTIVES

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

- Understand the basic concepts of providing fire protection in buildings.
- Define fire resistance and understand how it is determined.
- Identify the primary laboratory fire tests and the characteristics they assess.
- Describe research being conducted to enhance fire protection capabilities.
- Explain the ways in which smoke and fire containment is achieved.
- Describe the various types of fire protection systems.

Case Study

Figure 6-1 The First Interstate Bank fire in Los Angeles.

Fire broke out on the 12th floor of the 62-story First Interstate Bank high-rise in Los Angeles, California, on May 4, 1988 (**Figure 6-1**). The building was of Type I construction—a steel frame with spray-applied fireproofing. Automatic sprinkler protection was in the midst of being installed in the building, but the valves from the risers to the sprinkler system on the fire floors were closed.

Fire quickly spread up the side of the building through autoexposure and glass curtain wall panel failure, as well as through the gap between the unbroken exterior glass curtain wall panels and the floor slab. In total, 20 handlines from 4 standpipe risers were used to eventually stop the fire at the 16th floor. Dozens of fire companies were required to bring the fire under control. The danger of a significant structural collapse was a major concern during the firefight.

A postfire investigation revealed that the spray-on fireproofing on the steel was of good quality and exceptionally (and unusually) well applied. The lack of fire blocking at the window curtain wall–floor interface, however, defeated the basic fire protection tenet of compartmentation by allowing the fire to spread through this gap. Active sprinkler protection would likely have kept the fire very small or extinguished it.

1. What is the quality of spray-on fireproofing in buildings across the United States, including your jurisdiction?
2. Given the volume of fire on the affected five floors of the First Interstate Bank, what was the potential for a complete structural collapse?
3. How do fires spread vertically inside and outside of a building, and which features of building construction are intended to stop this progression?

Building Fire Protection: A Short History

From a historical perspective, fire *containment* has always been a primary objective. Fire fighters more than 200 years ago felt a sense of accomplishment if they held a fire to the neighborhood of origin, let alone a particular block. As apparatus and procedures improved, the fires grew smaller in magnitude, reducing down to small groups of structures and individual buildings.

The emergence of building codes in the early 1900s further advanced the elimination of **conflagrations**. The adoption of such codes strived to contain fires not only to a building, but also eventually within a building. Limiting fire spread from building to building is accomplished through several means: restrictions on the area/height of a building, limits on the combustibility of roofs and exterior wall surfaces, minimum separation distances between buildings, limits on openings in exterior walls (doors and windows), and fire-resistive exterior walls. Although all of these features may not be found in all buildings (especially older buildings, which often predate modern code provisions), they form the basis for preventing fires from growing into a conflagration.

Limiting the spread of fire within a building has the added benefit of contributing directly to life safety. Preventing a fire from spreading through a structure protects its inhabitants. This is achieved through the use of **fire-rated** floors, protection of vertical openings such as stairs and elevator shafts, **compartmentation** in the form of **fire walls** and **fire partitions**, fire-resistive construction (e.g., rated columns and beams to prevent collapse and spread of fire), and the use of fire protection systems such as fire sprinkler systems and fire alarm systems.

Life safety for building occupants is, of course, a primary concern in fire protection. Among the most important elements of life safety are proper means of **egress** (exits) and protection against hazards (based on occupancy and the capability of self-preservation). Although life safety for occupants has been addressed for more than 75 years in building codes, incremental improvements are still being made based on tragic, real-world experiences.

Recently, fire fighter safety has become an explicitly stated goal in building and fire codes. A handful of regulations have been based on this goal over the years, including the requirement to place shaftway signs on the exterior of buildings adjacent to elevator and other shafts. This recent change of policy has resulted in a specific chapter in the *International Building Code* dedicated to fire fighter safety as well as general provisions that advocate for fire fighter safety. Very recent code changes to the *International Residential Code* have been made to protect exposed basement wood joists. Recognize, however, that many homes existing today do not have such protection; these code building and residential code improvements do not apply retroactively to existing homes.

Fire Terminology

Confusing Language

Many terms are used to describe materials in advertising or building codes. Some examples are fire rated, fireproof, **flameproof**, self-extinguishing, slow burning, **flammable**, nonflammable, **fire retardant**, nonburning, **fire resistant**, and **noncombustible**. It is uncertain what these terms actually mean and the exact conditions of fire testing required to earn these labels. A sample examined in one fire test may be self-extinguishing, for example, whereas it may rate as combustible if another test is used. Get the full information on the fire tests and the standards used before accepting any claim of superior fire performance.

Although the preferred word is *flammable,* the term *inflammable* may still be encountered. For many years, the NFPA has striven to eliminate this term from fire protection literature because it is confusing—some people may think it means "not flammable." If it disappears from use, it will soon become archaic, its usage dropped and the confusion avoided.

Noncombustible Buildings

Some buildings are described in codes as noncombustible. This description is not technically accurate. The local fire officer should know exactly what this means. The noncombustibility requirement is limited to certain designated components, so noncombustible buildings can contain significant combustible components, including cornices, wooden interior balconies, and sheathing.

Fire Resistance Distinguished

As a fire fighter, you must distinguish between two uses of the term *fire resistance*. **Fire resistance rating** is a quality ascribed to a wall, floor, or column assembly that has been tested in a standard manner to determine the length of time for which it remains structurally stable (or resists the passage of fire) when attacked by a standard fire. **Inherent fire resistance**, in contrast, is a structural member's resistance to collapse by fire because of the nature of its material or assembly. A heavy wood beam, for example, takes longer to fail from a fire than does a 2 × 4. Likewise, a light steel beam will absorb heat faster and thus fail sooner than will a heavier beam. A masonry wall, itself quite fire resistant, may fail because of the lateral thrust of an elongating steel beam. The inherent fire resistance of a structure has never been formally rated or required by law.

By experience and tradition, the fire service has developed some criteria for determining the inherent fire resistance of a particular type of construction. Unfortunately, these criteria are imprecise. Many times fire fighters risk life and limb without really knowing the degree of risk and without performing any risk/benefit calculation. The generally accepted indications of imminent collapse, such as floors or roofs softening, water flowing through bricks, smoke pushing out of mortar joints, and strange noises, are, at best, grossly inadequate, even for buildings built many years ago. If these warning signs are solely relied on to alert fire fighters to danger in today's lighter buildings, disasters will be the result.

Some codes include a "protected combustible" classification. Combustible structures are protected with gypsum board and wood assemblies that have passed the standard fire resistance test. When a combustible structure is involved in fire, no code provision, however well written and well meaning, provides real personal safety for the fire fighter. The building is the enemy, and you must know the enemy.

Early Fire Tests

Toward the late 1800s, it became apparent that building structures with "fireproof" or noncombustible materials provided no guarantee against tremendous fire losses. As steel-frame buildings emerged, the necessity for protecting the steel from the heat of fires became understood. A 1921 book titled *Fire Prevention and Fire Protection as Applied to Building Construction* gives fascinating information on the early designs of fire protection for such structures, some of which—such as the Government Printing Office in Washington, D.C.—are still standing. At that time, construction engineers were expected to design buildings "on the job." Destructive fires in these and other unprotected buildings built with innovative but untested techniques helped to bring about the realization that standards and test procedures for fire-resistive construction were necessary.

Wood floors received the earliest attention, as columns were considered to present no problems. One school of thought claimed that if such floors were designed to resist collapse, then they also presented a risk for general collapse of the building. Another school of thought believed that if a wood floor was designed to resist a collapse early in a fire, then the walls would remain standing. The dilemma posed by these opposing viewpoints, it was decided, could be resolved by designing "fireproof" floors.

In 1890, the first fire test of a fireproof floor assembly in the United Sates was conducted for the Denver Equitable Building Company. Hollow-tile floors were tested. The test revealed that porous hollow tiles set in end construction (tile cells at right angles to beams) were superior to dense tiles set in side construction (tiles cells parallel to beams). The floors were subjected to load, shock, fire, and water, and continuous fire tests (24 hours at 1,300°F [704°C]).

Six years later, the New York City Department of Buildings conducted a series of tests on fireproof floors using brick kilns as test furnaces. The central panel of the floor was loaded to 150 pounds per square foot (psf). A wood fire was built on a grate and maintained at 2,000°F (1093°C) during the last four hours. After the fire, a hose stream was applied and the floor was reloaded to 600 psf for 48 hours, with the final load resting on the arch rather than the beam.

Other tests were conducted at Columbia University. Later, gas or oil fires were used in tests for better control. Further, in addition to structural integrity, requirements that the floor must not permit passage of fire were developed.

Between 1896 and 1916, not much fire testing was done on columns. However, the testing that was conducted showed cast iron to be superior to unprotected steel.

Standards for Fire Resistance

New York's Parker Building fire in 1908, the Equitable Building fire in 1912, and the Baltimore conflagration in 1904, which involved many "fireproof" buildings, convinced many people that there was a dire need to develop standards and test procedures to ensure truly fire-resistive construction Figure 6-2.

The effort to develop standards for fire resistance brought together the National Bureau of Standards (NBS; today known as the National Institute of Standards and Technology [NIST]), Underwriters Laboratories, Inc., the NFPA, and both capital stock and mutual insurance interests (insurance companies have a financial interest in the "successful" outcome of a fire, one in which the claims they need to pay are minimized). Fire resistance tests were conducted during World War I in 1917 and 1918, and early standards were developed that have been preserved in substantially the same form ever since.

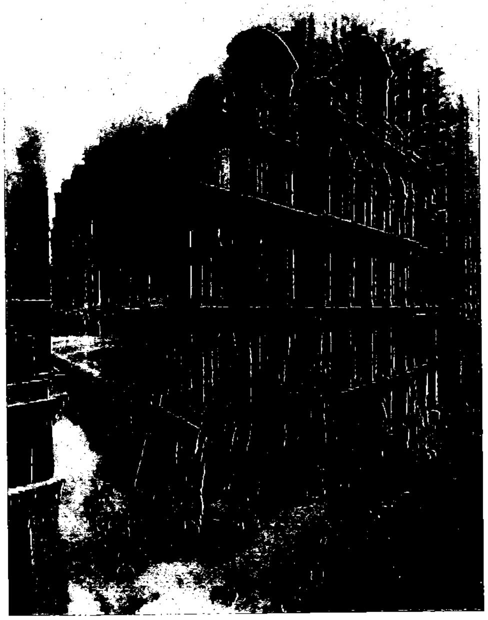


Figure 6-2 The Equitable Building fire in 1912.

Courtesy of Irving Underhill/Library of Congress.

Materials and assemblies may be classified based on their fire resistance, or, more accurately, based on their fire endurance—standards for these capabilities are prepared by different organizations. Committees from each organization periodically review and update the standards. The three following standards, while prepared by separate organizations, are very similar in content and structure:

- NFPA 251, *Standard Methods of Fire Tests of Building Construction and Materials* (National Fire Protection Association). This final edition of standard was issued in 2006; the NFPA has decided not to update the standard because, from a technical standpoint, it has fallen behind UL 263 and ASTM E-84, and there is desire to eliminate duplication of standards.
- UL 263, *Fire Tests of Building Construction and Materials* (Underwriters Laboratories, Inc.).
- ASTM E-119, *Methods of Fire Tests of Building Construction and Materials* (American Society for Testing and Materials).

What Does Fire Resistance Mean?

It is important to understand what sort of protection fire resistance is supposed to provide:

- Fire resistance of columns is concerned with resisting collapse.
- Fire resistance of floors is concerned with resistance of passage of fire and collapse.
- Fire resistance of walls is concerned with passage of fire and collapse.
- Fire resistance of fire doors is concerned with passage of fire.

It is equally important to understand what sort of protection fire resistance is *not* supposed to provide:

- Fire resistance, by itself, is *not* specifically directed at ensuring life safety. Many lives have been lost in fire-resistive buildings. Nevertheless, to the extent a building and individual fire-rated components continue to stand under fire attack and allow occupants to evacuate and fire fighters to bring the fire under control, fire resistance can be considered a life safety feature.
- Fire resistance is *not* specifically intended to provide **smoke control**. For example, metal-clad wood fire doors generate carbon monoxide (CO) as they burn. Furthermore, while some earlier fire resistance systems provided smoke containment, it is not part of the three previously mentioned fire resistance standards.
- Fire resistance is *not* concerned with the dollar loss due to fire. There have been huge financial losses in fire-resistive buildings.

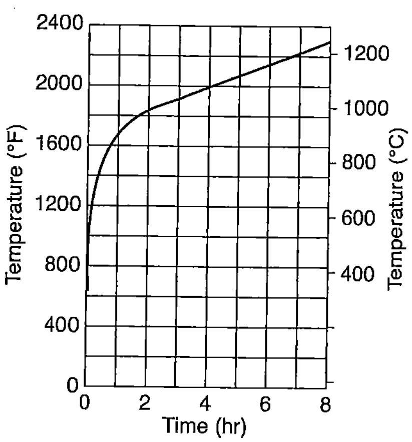
Fire Resistance Testing

Essentially, the provisions of the test standards—NFPA 251, UL 263, and ASTM E-119—require a reproducible test fire, a consistent method for conducting tests and classifying results, and specific instruction on the selection and preparation of test specimens. The objective of these provisions is to ensure uniformity in testing.

The reproducible fire used in the test procedure follows a **standard time–temperature curve** (Figure 6-3). This curve has remained essentially unchanged for more than 80 years. This single curve, created as the result of a small series of test burns in vacant buildings in 1918, represents the temperatures recorded in those tests. The curve does not represent fires of different sizes or fuels, particularly "modern" fires.

In the fire resistance test, samples of typical structural elements are exposed to the standard fire in a test furnace equipped with gas-fed burners. The furnace temperatures are regulated by computer to follow the test curve.

The minimum sizes for test specimens are as follows: columns, 9 feet (2.7 m); beams and girders, 12 feet (3.7 m); partitions and walls, 100 square feet (9.3 m^2); and floors and roofs, 180 square feet (16.7 m^2). The load-bearing structural elements are loaded with the prescribed weight for the assembly being tested. The unit passes the test as long as it successfully resists the superimposed load and, in the case of partitions, walls (Figure 6-4), floors (Figure 6-5), and roofs, resists the passage of fire.



1000°F	(538°C)	....	at 5 minutes
1300°F	(704°C)	....	at 10 minutes
1550°F	(843°C)	....	at 30 minutes
1700°F	(927°C)	....	at 1 hour
1850°F	(1010°C)	....	at 2 hours
2000°F	(1093°C)	....	at 4 hours
2300°F	(1260°C)	....	at 8 hours ot over

Figure 6-3 The standard time–temperature curve as shown in NFPA 251.

Figure 6-4 A wall assembly fire resistance test.

Figure 6-5 A floor fire resistance test.

Columns have several **thermocouples peened** into the columns. When the average temperature exceeds 1,100°F (593°C) or any of the thermocouples' temperatures exceeds 1,300°F (704°C), the test is ended and the specimen fails.

A floor structure or wall structure must not develop conditions that would ignite cotton waste on the unexposed surface or permit an average temperature rise on the unexposed surface of 250°F (121°C). Under many circumstances, a hose stream is applied to the hot assembly immediately after the fire test to assess its stability when hit by water from a fire hose.

Floor and roof assemblies are often tested under restrained and unrestrained conditions. Essentially, the assemblies are secured on the ends and not permitted to move. This, of course, is a more severe test for these assemblies, given that the expansion of the structural elements as a result of the test furnace heating may cause them to distort and buckle when restrained.

Assemblies that pass the test are rated in units of hours—for example, 1, 2, or 3 hours—depending upon how long the test unit survived the test fire. As appropriate, restrained and unrestrained designations are also indicated. Rated units are listed in references such as the *UL Fire Resistance Directory*, which is published annually. Based upon such **listings** (being "listed" is not the same as being "approved"), local authorities such as the buildings department may "approve" (permit for use as being acceptable to the local jurisdiction) use of these specific materials and assemblies.

Minimum Requirements for Fire Resistance Listing

A listed assembly meets the minimum requirements needed to pass the test. Thus, all components assembled as specified in the listing are required to meet that specific listing. Critics suggest that the NFPA 251, UL 263, and ASTM E-119 standards contain redundant precautions. In reality, nothing could be further from the truth. Owing to the nature of the testing process, the listed assembly is the minimum-quality structure capable of passing the test. Not requiring assemblies to achieve this minimum standard could give a supplier an advantage over its competitors that do meet the standard, as the latter suppliers would inevitably have higher costs.

At times, buildings departments may approve variations from the listing. Such a departure from the listing means that the assembly installed is probably not equivalent to the listed assembly.

The listings are not like a restaurant menu from which one can select one item from column A and another from column B. Put simply, components should not be considered apart from the tested and listed assembly. A very common fallacy is the belief that fire resistance can be achieved simply by nailing up some 5/8" (15.9 mm) "fire-rated" gypsum board. In reality, the fire rating comes from the listing of the *entire* assembly, not the individual components within that assembly.

Also, it is important to recognize that the unit being tested may be seriously damaged or effectively destroyed in passing the test. Indeed, fire resistance standards are often misinterpreted owing to misperceptions about what the testing results mean. A 2-hour fire resistance rating does not mean the building will be relatively undamaged for 1 hour—fire damage can be quite severe even for short exposures. Instead, the fire resistance rating means that *if* the building reacts to the fire in the same manner as the specimens did for that particular type of construction in the test, *and if* the actual fire load (fire impact) does not exceed the fire test load, *and if* the duration of the fire does not exceed the time specified for the components involved, *then* the structure should survive the fire.

However, the time ratings given to fire-resistive assemblies *do not* relate to the real time in an actual fire. Rather, the ratings provide a relative *measure* of comparison, comparing one assembly's duration of endurance to another assembly's duration; a 2-hour fire-rated assembly simply has greater fire endurance when compared with a 1-hour fire-rated assembly.

In the wake of the World Trade Center disaster in 2001, increasing criticism has been leveled at the fire resistance test, particularly calling into question its ability to represent the "real" fires of today. The bottom line when considering fire resistance ratings is that you need to understand what the test actually represents and what it does *not* represent. Fire resistance—more specifically, fire resistance–rated assemblies—does not necessarily mean noncombustibility. Many listings of assemblies include combustible components, typically wood beams or studs.

The fallacy of arguing that fire resistance–rated assemblies represent a completely safe working platform lies in the fact that the test standard was originally developed for noncombustible floors assaulted by fire *only from below*. In reality, structures that incorporate wood beams or lightweight trusses, for example, might potentially be attacked by fire from both above and below and by fire starting or moving into the combustible void space in the middle of the assembly. For example, ectrical fire starting inside the truss of a 1-hour fire-rated floor assembly is not even considered under the test standard. If a fire starts inside the assembly, forget about the fire rating; no such rating exists. This situation is a major deficiency in the test standard—the standard does not recognize the fact that nearly all such assemblies have electrical wiring running within them.

Fire resistance ratings for building materials must be distinguished from flame spread ratings. It is common (but mistaken) practice to speak of "fire-rated tile." The term is meaningless.

Fire resistance ratings are concerned with the length of time a particular building assembly will continue to perform its structural and/or barrier function in the face of an assault by a standard fire test. Flame spread ratings are concerned with the rate at which fire spreads over the surface of a material, the smoke it develops, and the fuel it contributes to a fire. These two terms are not interchangeable, but in some cases, a single material may be evaluated in terms of either its fire resistance rating or flame spread, depending upon the way it is used. For example, when acoustical ceiling tile is part of a fire-resistant floor and ceiling assembly, its ability to act as a barrier to the passage of heat is of prime importance. In contrast, when acoustical tile is used solely for its sound-deadening and decorative qualities, such as when tiles are directly adhered to the underside of a concrete floor, then its flame spread rating is of prime importance. As part of the interior finish of a building, its ability to spread flame is a life safety concern. In many cases, both fire resistance and flame spread ratings may be concerns.

The overall fire resistance rating of a building is an accumulation of the scores for hundreds of components. These items are built and installed by persons of all levels of competence. Even though building codes call for certain levels of fire resistance, the entire building as one single unit is not tested. The failure of only one of many elements may be disastrous. Of course, only a real fire is the ultimate test of a building's ability to resist the effects of a fire.

Moreover, one of the most important factors in fire spread within buildings is the interior finishes on walls and ceilings. Fire history is replete with examples of deadly fires in which interior finishes played a deadly role, including the flammable decorations in the Boston Cocoanut Grove fire of 1942, the 1984 haunted castle polyurethane-fed fire at the Great Adventure amusement park in New Jersey, and the 1977 Beverly Hills Supper Club in Kentucky in which carpeting on the walls aided fire spread. The most recent fire where interior finish played a critical role occurred at the Station nightclub in West Warwick, Rhode Island, where 100 people were killed when indoor pyrotechnics ignited polyurethane foam padding on the walls surrounding the performance platform.

Testing and Rating Materials

The first attempts to deal with flame spread by codes failed due to inexact, legally unenforceable language, such as "flame spread no greater than wallpaper." Developing adequate tests is costly and time consuming. Tests must be consistent; that is, tests performed in the same apparatus on the same material should produce the same results. Tests also should be reproducible; that is, others using similar equipment and procedures should obtain the same results.

Steiner Tunnel Test

The basis for regulation of flame spread today is found in NFPA 255, *Standard Method of Test of Surface Burning Characteristics of Building Materials*, commonly referred to as the **Steiner tunnel test** (Figure 6-6). The test was developed by the late A.J. Steiner at Underwriters Laboratories, Inc. and is also known as ASTM E-84 and UL 723. Essentially, a test sample 25 feet (7.6 m) long and 2 feet (61 cm) wide forms the top of a tunnel or long box. A gas fire is lighted at one end, and fire progresses along the underside of the top of the box or test panel. Window panels on the side of the tunnel along the length of the tunnel allow for observations of the progression of flame spread.

There are two comparison points in evaluating test results. The flame spread over inorganic reinforced cement board is set at 0. The flame spread over red oak is set at 100. Tests have shown that fire can reach the end of a red oak test panel in 10 minutes. Other materials tested are rated on a scale determined by these points. The formula by which the flame spread index is calculated can be found in NFPA 255.

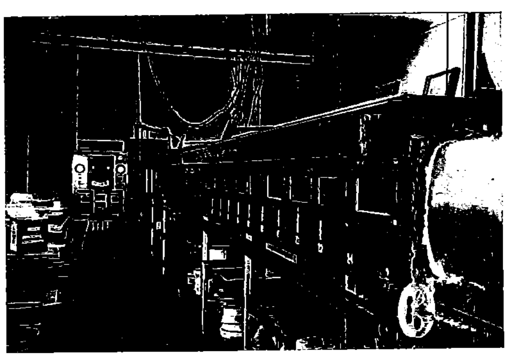


Figure 6-6 The Steiner tunnel test.

Courtesy of Herbert Blenstein.

Flame spread of surface materials is classified as follows:

- Class A: 0–25
- Class B: 26–75
- Class C: 76–200

Most building and fire codes have requirements for ceiling and wall surfaces based on the tunnel test standard. A typical requirement might be for a Class A flame spread rating for exit stairwells in hospitals. Sometimes higher flame spreads are permitted for sprinklered buildings. The model building codes allow for a reduction in the class level when sprinkler protection is available, but in no case can the rating be less than Class C (i.e., A→B, B→C, C).

When the tunnel test is run at Underwriters Laboratories, Inc., **smoke developed** is also measured and indexed. Smoke developed is calculated by measuring the obscuration as the smoke passes a photoelectric cell placed in the stack from the test tunnel. Again, the loss of light from inorganic reinforced cement board and red oak are used as benchmarks. Materials with smoke-developed ratings of 300 or more can be expected to generate substantial amounts of smoke. Only light obscuration is measured in this aspect of the tunnel test—not any of the other effects of smoke or gases, such as toxicity or irritation.

The Steiner tunnel test is widely accepted as a flame spread testing standard. It is almost impossible to read the literature for commercially installed ceiling tiles without encountering a reference to the flame spread rating. This is not wholly the case in the home market. Homeowners generally are unaware of the flame spread testing standard or how it is applied to the tiles they buy.

In some cases, manufacturers have stressed low flame spread ratings, neglecting to point out that the material advertised received a very high smoke-developed rating. All materials listed by nationally recognized testing laboratories are tested for both characteristics.

Radiant Panel Test

The NBS developed ASTM E-162, *Radiant Panel Flame Spread Test*. Samples for this test measure only 6 by 18 inches (15 by 46 cm) (Figure 6-7). For some materials, results from this test can be correlated with the Steiner tunnel test results, but no direct relationship should be assumed. The radiant panel test has been used to develop information after serious fires, but would probably not be valid evidence in a prosecution based on noncompliance with a code.

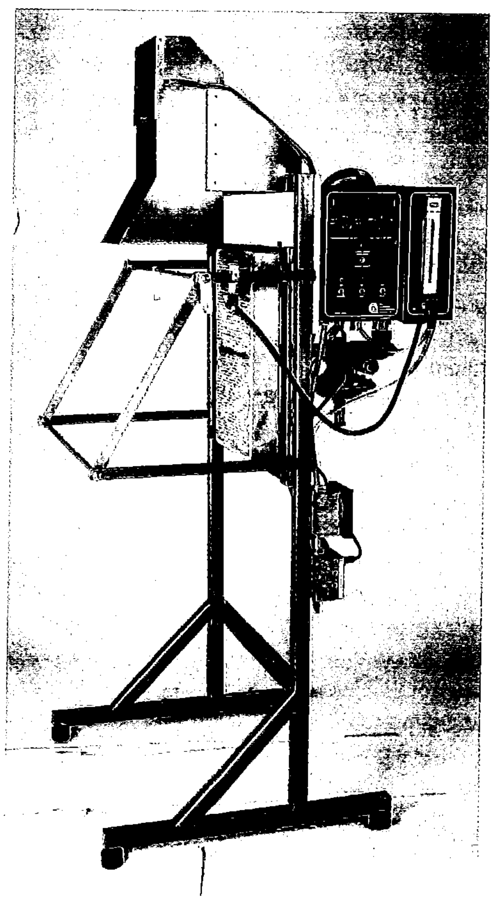


Figure 6-7 The radiant panel test.

Photo courtesy of The Govmark Organization, Inc.

FM Approvals Corner Test

The corner test developed by FM Approvals is designed to simulate an actual fire within the corner of a building (Figure 6-8). In the test, the walls are up to 25 feet high (7.6 m); the east wall is 50 feet long (15.2 m) and the south wall is more than 37 feet long (11.3 m). This test assesses, among other things, flame spread. It is considered a more realistic test than the Steiner tunnel test because the material is being tested in a more realistic configuration, as compared with the horizontal tunnel test.

Carpet Tests

Floor covering, specifically carpeting, has been an important contributing factor in a number of serious fires. In recent years, many tests and standards have been developed for carpeting. Commercial carpeting presently being manufactured is required to meet a test that measures ignitability of carpeting from a small source such as a dropped match or cigarette. It is a screening test (popularly known as the pill test), and seven out of eight samples must pass the test.

There is also a test to rate carpeting for its ability to spread flame when attacked with a greater ignition source than a cigarette. This test is NFPA 253,

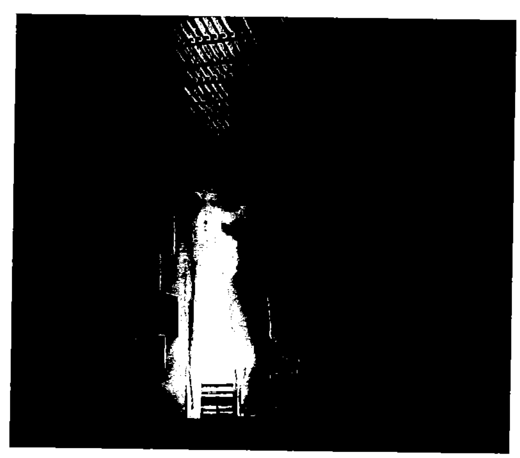


Figure 6-8 The FM Approvals corner test.

Standard Method of Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source (also known as ASTM E-648).

The tests cited here are not intended to test carpets for use as wall finish. ASTM E-84 and NFPA 265, *Standard Methods of Fire Tests for Evaluating Room Fire Growth Contribution of Textile Coverings on Full Height Panels and Walls*, are the appropriate tests for this situation.

Critical Radiant Flux of Floor Covering Systems Test

The Critical Radiant Flux Test (NFPA 253) measures a material's ability to resist flame spread. The result derived from the test is the **critical radiant flux (CRF)** of the sample. This is the amount of external radiant heat energy (measured in watts per square centimeter) below which a flame front will cease to propagate. The higher the CRF number, the less flammable the carpeting.

This test uses the radiant panel set at an angle. The carpeting sample is set flat in its normal position. The sample should be tested with the intended underlayment. If the carpeting is flammable, the flame spread will probably increase; that is, the CRF will decrease if an underlayment is present. The underlayment acts as an insulator, keeping the heat from the carpeting from being dissipated to the floor.

Where regulated, the model building and fire codes consider two classes of interior floor finish ratings:

- Class I: CRF minimum ≥0.45 watt/sq cm
- Class II: CRF minimum ≥0.22 watt/sq cm

A reduction in class is permitted in spaces protected by an approved automatic sprinkler system.

CRFs of carpeting involved in several serious fires have been determined. Thus, when regulations are adopted specifying a minimum interior floor finish rating, that may signal a relationship to specific fire danger that is not so apparent in other occupancies.

Don't Be Mousetrapped

Fire departments should be very wary of conducting their own tests. Tests that prove that a particular product is the answer to all problems should be suspect. Testing is a difficult and exacting profession. Leave it to the experts.

It is also difficult and sometimes impossible to determine the fire resistance rating and flame spread characteristics of materials already in place in actual buildings. Both fire resistance–rated and non-fire-resistance–rated assemblies and low and high flame spread materials can have the same appearance.

Field testing can be dangerous. In one case in an eastern city, the fire department was conducting a campaign against flammable decorations. An inspector examined a display for a popular brand of blended whiskey. He decided to test the flammability with his lighter. The display was indeed flammable—the ensuing fire went to multiple alarms. The city paid a heavy judgment and two fire fighters were seriously injured in the fire response.

Research

Research work is under way to bring testing up to today's fire dynamics and replace the standard time–temperature curve. This research will be beneficial to all concerned with fires in buildings.

For example, changes have been made to the U.S. building and fire codes as a result of the World Trade Center collapse on September 11, 2001. Changes were made to improve sprayed–on **fireproofing** in terms of adhesion and cohesion of the substance, mandate wider stairs in some high-rises, provide for a separate high-rise fire fighter stairwell and improved fire fighter elevator access, and require in-building radio signal amplification in high-rises and other structures where communications among fire fighters and other responders might be difficult. In addition, the very first provisions to allow special "hardened" elevators (elevator cabs and shafts that have been fortified against extreme events such as explosions) for civilian egress during an emergency were put in the building code.

Nationally, fire research has taken an interest in building construction and fire fighter safety. In 2004, NIST issued a report on a series of tests in Phoenix, Arizona, in wood-frame buildings. One of the results of the test was the observation that thermal imagers, while valuable for assessing fire spread, did not offer any help in establishing roof deck temperatures directly under the roof. In the experiments using roofs with both clay tile and asphalt shingles, no observable changes on the camera screen were seen prior to collapse. Instead, water from hose streams cooled the roof and radiation from the fire and smoke plumes "washed out" the fire's signature; as a consequence, the thermal imager did not offer assistance as to the actual temperature conditions of the roof itself. Additional recent testing by NIST has attempted to develop collapse indicator equipment using sonar, laser, and vibration analysis. A prototype vibration analysis tool, "HOBS" (Health of Burning Structure panel), has been developed to monitor vibrations in a structure that might be a precursor to a collapse.

In 2008, Underwriters Laboratories, Inc., with the assistance of the Chicago Fire Department, issued a report entitled "Structural Stability of Engineered Lumber in Fire Conditions," which provided a sobering set of collapse comparisons for "legacy" construction (traditional wood members) versus lightweight structural members (wood I-beams and trusses). In a simulated basement fire involving exposed lightweight wooden I-beams, collapse occurred in a mere 6:03 minutes. The legacy 2- by 10-inch (51 by 254 mm) beam construction outlasted lightweight construction by a 3:1 time margin. Another valuable lesson was also learned: carpet and other floor coverings may conceal the true fire conditions underneath the floor from a thermal imager.

Containment of Fire and Smoke

Generally speaking, there is a hierarchy of fire-resistive assemblies. Building codes specify the level of fire resistance in hours and the number and type of penetrations permitted. Here is a list of fire-resistive assemblies:

1. Fire walls are typically 2- to 4-hour fire resistance rated and are used to create separate buildings. They are defined in the *International Building Code* as "a fire-resistance-rated smoke-tight wall having protected openings, which restricts the spread of fire and extends continuously from the foundation to or through the roof, with sufficient structural stability under fire conditions to allow collapse of construction on either side without collapse of the wall."
2. Fire partitions are typically 1-hour fire resistance rated and are used to create fire-resistive corridors and to separate tenant spaces in covered mall buildings. They are defined in the *International Building Code* as "a vertical assembly of materials...designed to restrict the spread of fire in which openings are protected."
3. **Fire barriers** are typically 1- to 2-hour fire resistance rated and used to enclose shafts, exit stairwells, exit passageways, and **horizontal exits**, and to separate spaces from certain hazardous areas. They are defined in the *International Building Code* as "a fire-resistance-rated vertical or horizontal assembly of materials... designed to restrict the spread of fire in which openings are protected."

Openings in fire-resistive assemblies are required to be fire resistance rated as well. For instance, heating, ventilating, and air-conditioning (HVAC) systems passing through fire-resistive assemblies must be provided with **fire dampers**. Many fire dampers are mechanically operated using a fusible link that drops a metal "curtain" or blade inside, blocking passage of fire **Figure 6-9**. Other types of fire dampers use pneumatic or electric activation.

Fire dampers typically receive very little attention once they are installed. Shifting or movement of the duct they are attached to can put them out of alignment, preventing the blade or curtain from moving properly. For this reason, fire dampers should be checked periodically. Combined fire and smoke dampers, typically used in **smoke barriers** and smoke partitions, also require periodic maintenance.

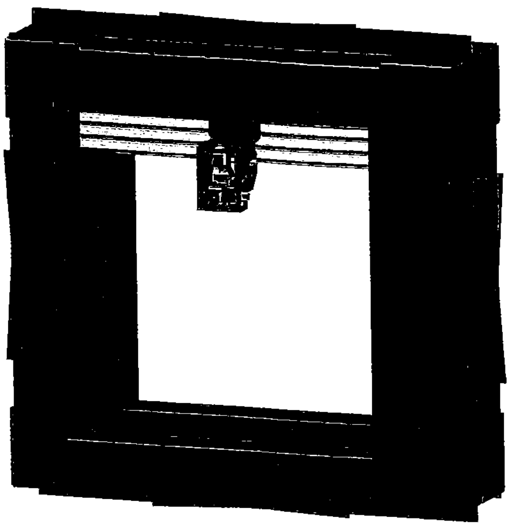


Figure 6-9 A fire damper with interior "curtain."

Courtesy of Ruskin Air Management Limited.

Fire Doors

Fire doors can have fire protection ratings ranging from 20 minutes to 3 hours, depending on the type of fire resistance–rated assembly the fire door is located in. One of the most important aspects of a fire door is its ability to close and latch closed. There have been numerous disasters in which the door closer or latch failed (e.g., because it was broken or blocked) and fire spread throughout the building. A New York high-rise fire in 1998 killed four people when the occupant of the apartment in which the fire started jammed a welcome mat under the corridor fire door, allowing fire and smoke to travel up through the building.

A fire door was installed in the American History Museum many years ago over the objections of the Smithsonian Institution staff. It stopped a raging fire from destroying the Star-Spangled Banner. An official who had fought against the fire door later said, "I learned one thing in this investigation. If you are building a building to last 75 years, it will have a major fire, so fire is a design criteria."

Fire losses would be greatly reduced if designers and developers all adopted this point of view. Shopping malls have minimum horizontal barriers, which can allow smoke to pollute an entire mall. One Virginia mall has had two transformer fires that led to multimillion dollar losses owing to its lack of fire barrier features. Fire doors are tested using NFPA 252, *Standard Methods of Fire Tests of Door Assemblies*; UL 10B, *Fire Tests of Door Assemblies*; or the former ASTM E-2074 *Standard Test Method for Fire Tests of Door Assemblies, Including Positive Pressure Testing of Side-Hinged and Pivoted Swinging Door Assemblies*, which was withdrawn in 2007. A furnace is used to test the fire doors.

Fire doors may close by any of three methods:

- Swinging: the most common choice; used in corridors and stairwell openings Figure 6-10
- Sliding: typically found across openings in elevator shafts or stairwells in old factories Figure 6-11
- Rolling: used in large openings found in modern factories and warehouses Figure 6-12

Fire shutters are sometimes used in buildings. They are typically rolling fire doors used to protect small openings such as a ticket booth window in a rated corridor.

There are two types of fire door closure devices: self-closing and automatic. A typical example of the self-closing type is the room or stairway door equipped with an automatic door closer that closes the door after it has been opened Figure 6-13. Some stairway door closers are equipped with fusible links, which are designed to fail at a specific temperature and close the door when the heat from a fire is encountered. These links are not sensitive to smoke, however, so the stairway can be totally polluted with smoke before the link operates.

Fire walls with automatic fire doors intended to close only in case of fire are also equipped with fusible links. When the link melts, the overhead rolling door comes down, or the sliding fire door closes horizontally. Sliding fire doors may roll down a track by gravity or be pulled shut by a weight.

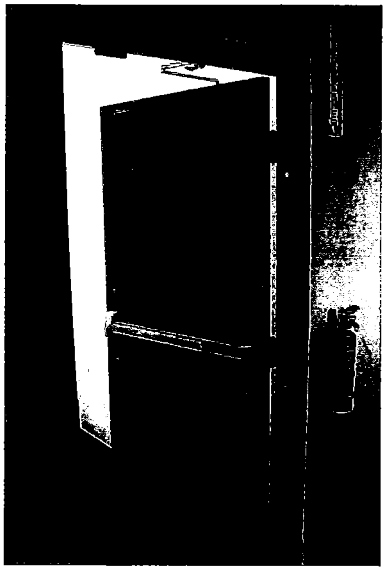


Figure 6-10 A swinging fire door.
Courtesy of Lawrence Doors.

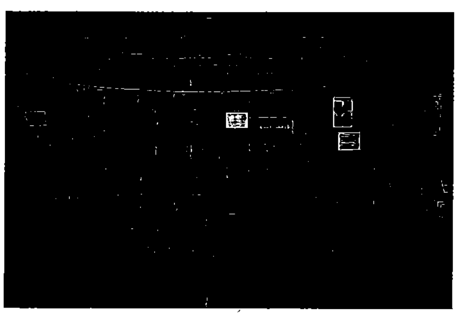


Figure 6-11 A sliding fire door.
Courtesy of Lawrence Doors.

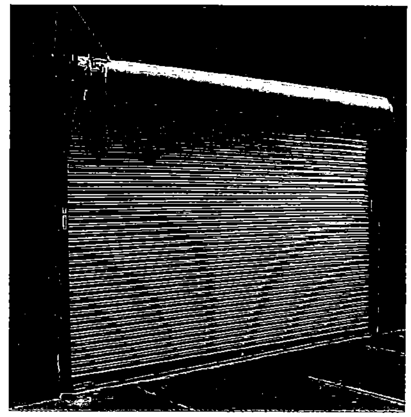


Figure 6-12 A rolling fire door.
Courtesy of Lawrence Doors.

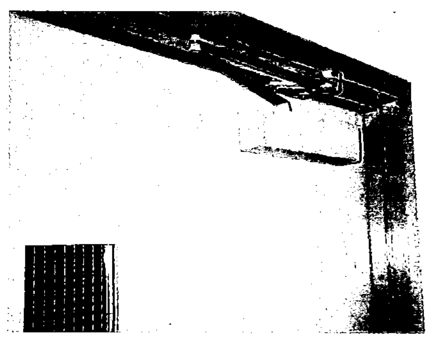


Figure 6-13 A self-closing device.
Courtesy of the estate of Francis L. Brannigan.

In either case, they should be checked by lifting up on the weight that holds the door open. The door should close properly without any assistance. Many existing fire doors are not in a state of readiness, and a variety of problems occur: broken closers, broken latches, mechanical blockages preventing them from completely closing (such as a broken track or a damaged drum on an overhead rolling fire door in a warehouse), or the proverbial door chock. Inspections and vigilance are necessary to ensure that fire doors remain in a good state of repair. Inspections should include the following items:

- Operating fire doors and shutters.
- Raising the counterweights of automatic sliding and counterbalanced doors to be sure they close.
- Inspecting doors for damage.

- Inspecting all hardware including latches, guides, and thresholds for proper function.
- Checking the fusible links of automatic closing devices to ensure they are free of paint and other foreign matter that might impair their operation. (Note that the fusible links of sprinklers in one paper plant did not operate properly because they were covered with oily paper dust.)
- Checking the proper operation of "door coordinators" that ensure that a set of opened fire doors ("leafs") close in the proper order, ensuring the gap between the doors is properly sealed Figure 6-14.

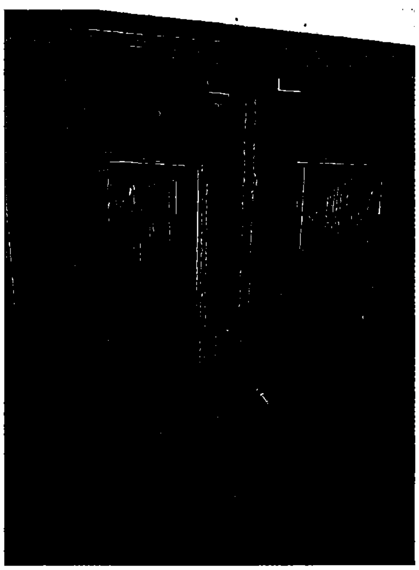


Figure 6-14 Originally, this pair of fire doors was to be self-closing with each door leaf shutting in a specific order, using a "coordinator." The door on the left is supposed to close first, followed by the door on the right. With door coordinator removed, the doors close in the wrong order. Note the extended metal plate on the right door's edge, which is supposed to seal the opening when both leafs are closed properly.

Courtesy of Glenn Corbett.

Branniganism

Fire fighters should not pass through a fire door without blocking it. Overhead rolling doors are particularly dangerous. In one case, the strength of all six trapped fire fighters was necessary to open a sliding fire door that had jammed into a bent retainer. The block should be removed when all fire fighters have returned through the opening.

As with many devices or materials, such closure devices may be completely inadequate to control smoke movement. Unfortunately, it is a common practice to block open self-closing doors.

Many fire reports note that the spread of fire and smoke in such occupancies was due to doors left open. The fact that stairway and corridor smoke and fire barrier doors are often blocked open, however, should not prevent fire departments from advocating for self-closing doors in apartment and hotel occupancies.

Non-fire-resistive buildings and older fire-resistive buildings were usually built without any consideration of the control of fire and smoke movement. As buildings are altered, there may be code requirements to upgrade the smoke and fire control. Some such alterations are more effective than others.

Using Smoke Detectors for Release

The development of the smoke detector has provided equipment that is sensitive to smoke and that may help to eliminate the problem of blocked open doors. In one method designed to prevent this practice, the doors are held open by electromagnets. The door latch system can be triggered automatically by the smoke detectors on either side of the door by fire, smoke alarm, or sprinkler water flow alarm. These doors should be designed to permit manual release as well. When an alarm cuts the current to the magnets, the door releases and becomes a typical self-closing door. Such a system is easy to test if the door contacts the magnetic latch when pushed to the wall.

Some doors are too heavy for magnetic latches, but may be held by mechanical latches that are released in the same way. Two-leaf doors should be checked to see that the doors close in the designed sequence as discussed previously. The roller that accomplishes this task is frequently damaged from constant use.

In other cases, the smoke-sensitive doors are controlled individually. One or two detectors (one on each side) trip a door as smoke is detected. In some cases, the detector is integral with the door closer. If the door is open and the detector senses smoke, the door is released. Such doors should not have latches to hold them open.

Stairwells

When it was learned from such fires as the 1908 Parker Building fire in New York that fire could extend open stairways in "fireproof buildings," the concept of compartmentation—that is, creating fire areas no larger than one floor—was developed. With this strategy, all connections between floors were designed to stop the spread of fires. For example, stairways in new buildings were enclosed and provided with self-closing doors with a fire protection rating. Outside metal fire escapes or true fire towers with "atmospheric breaks" (open to the outside air) were installed.

Many times, however, open interior "access" or "convenience" stairs are installed. These create a single fire area consisting of two or more floors, as was the case in the One Meridian Plaza fire in Philadelphia. The use of these open stairs allows smoke and fire to travel easily from one floor to the floor above.

Self-closing doors are considered a nuisance to many occupants who must move from floor to floor. For this reason, they may block stairway doors open with wooden wedges or other items. These makeshift devices are sarcastically called "four-hour fusible links" by inspectors. A few years ago, the United Kingdom mounted a campaign to enclose stairways and install fire extinguishers. To their chagrin, inspectors found that in some cases the extinguishers were used to block open the stairway doors.

In the United States, the stairway doors at the office of a well-known consumer safety advocate were blocked open with bundles of safety pamphlets. To counter this blocking problem, fusible links or door checks with integral 165°F (74°C) fusible links have been used. The closing of stairways does not often come naturally or easily. Indeed, the open grand staircase is often a crowning architectural feature of a monumental building. One of the most famous examples is found in the Paris Opera, where the volume of the stairway appears to be greater than that of the auditorium. An architect who worked in a city hall admitted that the open stairways could cause a loss of life, but felt that closing up the stairways would destroy the beauty of the building.

After several multiple-fatality hotel fires in the 1940s, an effort was made to enclose open stairways. In many cases, the corrective measures failed in that often the stairway was left open at the lower floors. In some building restorations, a "monumental" stairway was left unenclosed. The operative, yet strange, argument is that sufficient exits are already provided by protected stairways—a position that ignores the open stairway's danger as a transmitter of smoke and heat.

Horizontal Exits and Smoke Barriers

In past years, the concept of each floor being a single fire area was adequate. Today, however, floor areas in buildings have increased tremendously. This has necessitated horizontal exits. Horizontal exits (typically a 2-hour–rated wall with rated fire doors) are used to reduce travel distances and to subdivide (compartmentalize) floors.

From a firefighting perspective, this means that stairwells—and the standpipe hose outlets they often contain—are farther apart in multistory buildings. For that reason, building codes require hose outlets at the openings of a horizontal exit; this is to ensure that a sufficient number of hose outlets are available throughout each floor, avoiding excessively long handline hose stretches Figure 6-15.

Smoke barriers (typically 1-hour fire rated and with smoke-protected openings, including "smoke" dampers and door sweeps at the bottom of fire

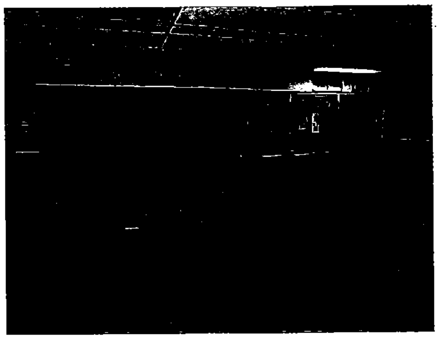


Figure 6-15 A noncompliant horizontal exit, missing the hose outlet.

Courtesy of Glenn Corbett.

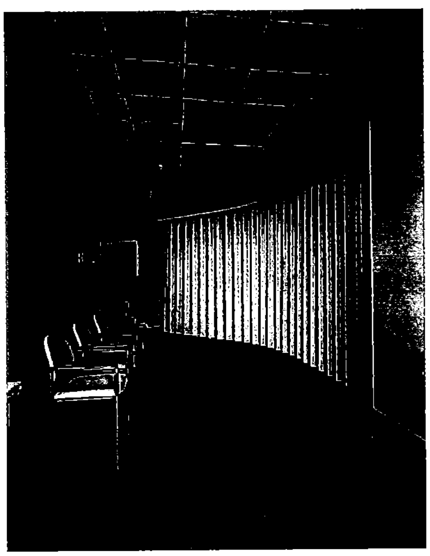


Figure 6-16 This smoke barrier allows safe egress of patients in a health care facility.

Photo courtesy of Won-Door Corporation.

doors) are used in health care facilities because they can be used to move nonambulatory occupants to a smoke-free area—it is difficult to move such individuals vertically Figure 6-16. Smoke barriers are also used in certain underground buildings. The horizontal barriers and smoke barriers are often resisted by building developers because closing down the opening to door size can damage architectural concepts aimed at highlighting a building's "openness."

Penetrations in Fire-Resistant Walls and Floors

It is a certainty that holes and penetrations will be created in fire-resistant assemblies when a building is being built. It is also a certainty that holes will be created during the life of the building. The reasons for the holes are numerous—pipes, conduit, wires, cables, and so on. The individuals creating the holes have no idea they have compromised the "fire integrity" of the wall or floor in question.

Holes must be properly sealed with listed through-penetration firestop systems. These fire-tested "systems" actually comprise a set of components, including special caulking, insulation, and supports. The entire system must be installed as designed and listed, otherwise, the system will not properly seal the opening in an actual fire. The firestop system must match the hourly fire resistance rating of the wall or floor it is protecting.

Escalators

Escalators are widely used in department stores and public occupancies. There is strong resistance to enclosing escalators. A number of methods of protecting the openings with various types of sprinkler or spray systems have been adopted in various codes.

One method involves the use of water spray nozzles directed downward through the opening. The fire department should be aware of this type of system because it can cause considerable water damage. Blame for this damage may be put on the fire department.

In some systems, a line of sprinklers is located around the escalators. They are typically used in conjunction with a glass partition around the opening that is 3 or 4 feet (91 or 122 cm) deep. The sprinklers are shielded from one another to prevent one sprinkler from cooling the other. Although these sprinklers may extinguish a nearby fire, they would have no effect on smoke or gases moving from a fire not in the immediate vicinity. This code-accepted method of sprinkler protection is an inadequate method to protect against vertical smoke migration. In short, life safety in such occupancies depends on the full sprinkler protection of the building and not partial protection at floor openings.

Thoughts on Smoke and Compartmentation

Fires produce huge volumes of heat, smoke, and gases. Starving the fire is one of the reasons sometimes advanced as a justification for compartmentation. In some cases, a fire has been cut off completely by compartmentation, but such cases are rare. The successes tend to be offset by tragedies that occurred when openings were made into otherwise unventilated compartments. In 1932, for example, eight fire fighters died when they opened the door on a smoldering fire in an unventilated storage room in the basement of New York's Ritz Tower Hotel. There have been a number of similar disasters.

Venting a fire, even at the risk of increasing its volume, is often necessary to make the conditions inside the fire building somewhat habitable for occupants and fire fighters. This necessity was recognized more than 100 years ago in the case of multistory fires in tenements in New York City. Packed with hundreds of immigrants, these buildings were deathtraps. A single wooden stairway, with wood and glass doors to tenant apartments, rose through the center of a building. Fire fighters learned early on that opening the roof over the stairway relieved the pressure on the upper floors, where potential victims were often at the windows. In 1903, the New Law Tenement House Act required, among many improvements, that all stairways be masonry enclosed, noncombustible, and have a skylight, so that fire fighters could easily vent the stairway.

In 1930, Assistant Chief Thomas Dougherty—a man far ahead of his time—wrote the book *Fire*. In it, he not only explained the necessity of ventilation, but also offered a design for automatic vents tripped by fusible links to be installed atop stairways. Some readers may object: "Automatic vents violate the cardinal rule, 'Don't vent until you have water.'" As with all rules, however, there are exceptions to this one.

Theaters where live actors perform on stage with scenery were the first buildings ever designed so that a fire could occur and the occupants would be protected from the combustion products. Automatic vents are provided above the stage to reduce the pressure on the proscenium fire curtain. The stage may burn out, but the audience has a greatly improved chance of escape. This concept evolved from the hundreds of deaths that occurred in theater fires. However, in Chicago's 1903 Iroquois Theatre fire, in which 603 people died, the stage vents were fixed in a closed position, and a gas light fixture blocked the curtain from closing. The program had boasted that the structure was "absolutely fireproof."

In 1919, the Holland Tunnel was being planned to connect New York and New Jersey under the Hudson River. It was designed to provide enough airflow through the tunnel to reduce the maximum amount of CO that could be generated by automobile exhausts to an acceptable level. The permissible level for CO was determined by having volunteers drive cars, until affected, around a "racetrack" cut into the coal mine at the Bureau of Mines Experiment Station near Bruceton, Pennsylvania. This was the basis for the permissible level for 8-hour exposure to CO. In the 1950s, the permissible level was cut in half. Tests showed that the airflow required to produce this level would be about 50 miles per hour (mph) (80.5 kph). Ole Singstadt, the design engineer, objected. He claimed that if a fire occurred in the Holland Tunnel, the occupants of cars in the tunnel would be incinerated. He argued for a triple tunnel arrangement, consisting of an air supply tunnel below the car tunnel and an exhaust tunnel above it, so that toxic gases would be vented vertically, directly above the fire. The Port Authority management balked, citing the cost. Singstadt, a tough, world-class engineer, pointed out that he was the only person in the world who could build the tunnel, and it would be built his way or no way. In the end, the Holland Tunnel was built his way.

In 1951, a truckload of carbon disulfide burned in the tunnel. Fire showed out the New Jersey-side vent tower, and it was necessary to use hose streams to cool the fans Figure 6-17. Everyone in the tunnel escaped, although unfortunately one fire officer died.

Figure 6-17 Two of the extraction fans in the Holland Tunnel failed to operate due to the tremendous heat of the 1951 fire.

© stf/AP Images.

The Eurotunnel (the "Chunnel") under the English Channel from England to France was completed in 1994. In this tunnel, cars and trucks are carried on trains. There are two separate train tunnels. A service tunnel between the two train tunnels is kept at a higher pressure than the train tunnels to exclude smoke. Access is provided through "smokeproof" doors. Reports estimated that 1,500 passengers could be evacuated from a burning train in 25 minutes. In November 1996, a fire in the Eurotunnel involving a train carrying cars and trucks did substantial damage, but no lives were lost.

Fire department ventilation has traditionally consisted of opening and breaking windows and cutting holes in the roof to allow smoke and heat to escape by gravity. A number of years ago, smoke ejectors were developed to increase the volume of airflow. Later, large fans were used to exhaust smoke, generally during overhaul. When this technique is used, it is necessary to prevent outside air from entering the air stream, thus diluting the flow for combustion products. Positive-pressure ventilation (PPV) has now taken hold across the United States.

Fire Protection Systems

In addition to the use of fire barriers as a means of fire containment and life safety, fire suppression and detection systems are another critical means of providing fire protection. What follows is a brief review of these systems, how they impact your firefighting efforts, and how you can use/support them.

Automatic Sprinkler Systems

For many years, automatic sprinklers were familiar only to fire protection personnel. Most citizens, including those who reported on fires, were completely unfamiliar with them. Times have changed, of course. One of the first questions many reporters now ask at serious fires is, "Is there a sprinkler system in the building?"

Automatic sprinklers are fast becoming a fact of life in buildings. They are being installed in new buildings in compliance with codes to reap the substantial benefits granted by such protection, and in recognition of the potentially catastrophic financial consequences, particularly liability, presented by serious fires. Slowly the need to retrofit sprinklers into buildings that should have been sprinklered when they were built also is being recognized.

Sprinklers were once almost exclusively installed in factory and mercantile buildings. For decades, the only sprinklered high-rise office building in the country was the headquarters of the National Board of Fire Underwriters. They are now included in every occupancy and are gaining greater acceptance in one- and two-family dwellings.

Sprinkler systems are installed under one of three different standards: NFPA 13, *Standard for the Installation of Sprinkler Systems*; NFPA 13D, *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes*; and NFPA 13R, *Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies* ("low-rise" in this case means residential occupancies four stories or fewer and less than 60 feet in height).

Types of Sprinkler Systems

There are four major classifications of automatic sprinkler systems. Each type of system includes piping for carrying water from a source of supply to the sprinklers in the area under protection.

- *Wet pipe systems:* These systems employ automatic sprinklers attached to a piping system containing water under pressure at all times. When a fire occurs, individual sprinklers are actuated by the heat, and water flows from the sprinklers immediately.
- *Dry pipe systems:* These systems have automatic sprinklers attached to piping that contains air or nitrogen under pressure. When a sprinkler is opened by heat from a fire, the pressure is reduced to the point where water pressure on the supply side of the dry pipe valve can force open the valve **Figure 6-18**. Then water flows into the system and out any opened sprinklers. Dry pipe systems are typically installed in areas of the building subject to freezing.
- *Preaction systems:* These are systems in which there is air in the piping that may or may not be under pressure. When a fire occurs, a supplementary fire-detecting device in the protected area is actuated. This opens a water control valve, which permits water to flow into the piping system before a sprinkler is activated. When sprinklers are subsequently opened by the heat of the fire, water flows through the sprinklers immediately, the same as in a wet pipe system. The advantage of these systems is that water typically will not flow if a sprinkler or pipe is broken, a desirable feature for areas that have easily damaged contents.
- *Deluge systems:* These systems have all sprinklers open at all times. When heat from a fire actuates the fire-detecting device, the deluge valve opens and water flows to, and is discharged from, all sprinklers on the piping system, thus deluging the protected areas, usually flammable liquid operations **Figure 6-19**.

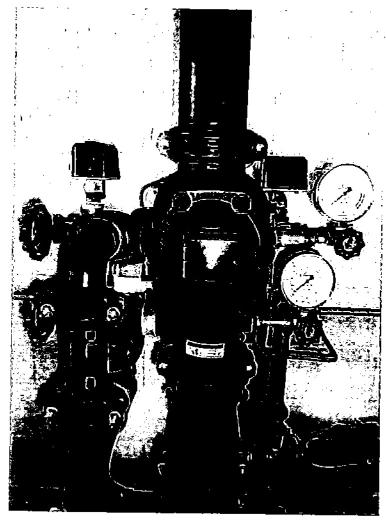


Figure 6-18 A dry pipe sprinkler valve at a fire training facility. The gauge on the top measures air pressure while the bottom gauge measures water pressure.

Courtesy of Glenn Corbett.

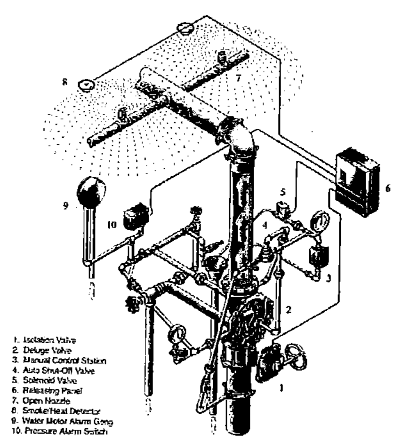


Figure 6-19 Water flows from all of the sprinklers in a deluge system as soon as the system is activated.

Courtesy of Tyco Fire and Building Products.

Design and Operation of Sprinkler Systems

Today, sprinkler systems are hydraulically designed, meaning that the pipe sizes selected are based upon the flow and pressure necessary to supply the sprinklers. With the exception of deluge systems, sprinkler systems are designed with only a certain number of sprinklers operating, not all sprinklers in the system. (The design would anticipate anywhere from 4 sprinklers on some residential systems to upwards of 50 sprinklers on some commercial building systems.) Each sprinkler is designed to flow a specific amount of water at a specific pressure to achieve a **density** of water (gallons per minute [gpm] per square foot [ft^2]) over a specific area of coverage (sprinkler operating area). Systems are designed to have an adequate water supply to meet this **demand area** (the anticipated overall size of the fire with all sprinklers operating).

The demand is based on the type of hazard presented. NFPA 13 has developed a set of occupancy classifications: light hazard, ordinary hazard group 1, ordinary hazard group 2, extra hazard group 1, and extra hazard group 2. See Appendix A for a list of examples. In general, the more significant the fire threat (e.g., museum versus flammable liquid spraying), the higher the density (i.e., the higher the flow and amount of water discharge).

It must be noted that although a system could have had an adequate water supply at the time of design and installation, the water supply may have deteriorated over time or the contents could have changed. As an area grows and develops, the demands on the public water supply could leave a sprinkler system with an inadequate flow or pressure. The change in building contents can cause the sprinkler system to be inadequate for the contents being protected.

Prewetting of exposed contents is an essential part of ordinary sprinkler operation. Sprinkler systems first slow, and then stop, the advancement of the fire through prewetting. Thus, the ability of the water to penetrate the material is key to sprinkler system effectiveness. Many palletized materials, however, are shrink-wrapped in an envelope of tight plastic. Pallets that have shrink-wrap on all sides including the top are considered fully encapsulated and are problematic to protect because sprinklers cannot prewet the material. In some cases, this has resulted in a failed sprinkler attack.

Sprinkler Installation Incentives

The two model building and fire codes provide different incentives for the installation of sprinklers. It has been estimated that there are over 200 incentives (reductions of the requirements) in the *International Building Code*.

Some who are opposed to these incentives or concessions argue that "they are giving away the store" to get sprinklers installed. Indeed, some fire protection professionals believe that a lot of fire protection eggs are being put into the one basket. The question is, "Who, if anyone, is watching the basket?" This question is discussed in detail later in this chapter. First, you will learn about the code-related, site development, and tax or insurance incentives that make sprinkler installation attractive.

Detailed information and provisions of specific codes are available from the National Fire Sprinkler Association. Typical code incentives or concessions generally are available in the following areas:

- Heights and areas
- Construction of corridors and tenant separations
- Interior wall, ceiling, and floor finishes
- Travel distances to exits
- Exit widths
- Standpipe requirements, hose station, and water flow
- Fire detection systems
- Draftstopping in attic spaces

Site development incentives:

- Fewer fire hydrants with greater spacing
- Reduced fire flow, small supply pipe
- Increased allowable distance from public access way
- Street width reduction
- Cul-de-sac allowances

Tax or insurance incentives:

- Elimination of value of sprinkler system from assessed valuation
- Property tax rebates
- Elimination of water department fees
- Insurance premium reductions

Opposition to Sprinklers

Not everyone is enthusiastic about the spread of requirements for automatic sprinklers. The concrete and gypsum industries and the manufacturers of spray-on fireproofing or other forms of protective encasement of steel beams object to trading off passive fire protection for sprinklers, citing the importance of protecting the structure of the building, the imperfection of mechanical systems, and the possibility of explosion, arson, or earthquake. In their view, sprinklers are a secondary defense. Another chief argument involves the loss of compartmentation. Compartmentation alone is not the solution to proper fire protection, however.

Furthermore, there is still much opposition to any requirement for retroactive installation of sprinklers. Although much of the opposition is financial, the specious argument that such requirements are unconstitutional has found some favor. Despite this, in the wake of the collapse of the World Trade Center in 2001, New York City passed legislation requiring sprinklers in existing unsprinklered high-rise office buildings. Sprinklering existing buildings can also help to bring existing buildings into compliance with current building codes.

Many opponents claim that sprinklers are ugly. However, there is no evidence that anyone ever refused to enter a building because it was unattractively sprinklered. Much of the cost, particularly of a retroactive installation, is caused by hiding the sprinkler system. If the argument of overall sprinkler cost is an issue, the fire department should be prepared with the cost of a bare bones system, and point out that aesthetic costs are the option of the owner, not a fire protection requirement.

The probability of a serious fire in any given office building or other building with many occupants is extremely low. It is also a fact, however, that in the typical unsprinklered glass-enclosed office building with interior stairways and a substantial fire load, the consequences of a serious fire during working hours could be very severe, with multiple fatalities.

Those who do not wish to provide the sprinkler protection often argue from "good experiences." In effect, they "need" fatalities to be convinced. They are unconvinced by rational arguments. Unfortunately, this is the argument often accepted by many public officials.

The charge is sometimes made that there is little experience with sprinklers in high-rise buildings. After the terrible Triangle Shirtwaist fire in New York City in 1911, the law was changed to require that all factories more than six stories in height be sprinklered. In the greatest migration of an industry in history, the entire garment industry moved into high-rise sprinklered loft buildings (rented factory space) in midtown Manhattan in the 1920s and 1930s. From these buildings, a large body of experience on successful sprinkler operations has been accumulated.

After the spectacular First Interstate Bank fire in Los Angeles in 1988, passage of a sprinkler law for all new and existing high-rise buildings in California seemed assured. However, this was not the case. All buildings built after 1974 and over 75 feet high (22.8 m) throughout the state of California must be sprinklered. In Los Angeles, all pre-1974 high-rises must be sprinklered. A law that would have required a statewide retrofit failed, however, according to one source, the rejection of this measure was due to the large number of state-owned buildings that would have required sprinklers.

Architects who know the codes can often circumvent sprinkler requirements. Because of the loss of fire fighters' lives in cellar fires, some cities have required sprinklers for basements in excess of a certain size, usually 2,500 square feet (232 m^2). One of the solutions is to cut the basement into sections with fire walls, so that no section is larger than the legal limit. It is likely that the fire doors will not function in such buildings, so the result can be a much more difficult and dangerous fire.

Another way to circumvent the regulations is to keep the building barely below the height at which sprinklers are required. Although the building was sprinklered, one of the authors of this text (Corbett) encountered a nine-story building that did not meet the definition of a high-rise because it was 74.5 feet (22.7 m) in height!

Much opposition to sprinklers develops from a lack of understanding of the threat of fire and the operation of sprinklers. In Evanston, Illinois, the Byer Museum was destroyed by fire in 1985. The unsprinklered Dallas Biblical Arts Museum was destroyed in a 2005 fire.

The National Gallery of Art in Washington, D.C., had a policy of not lending its art to sprinklered museums. The Smithsonian Institution was actually asked to return some works on permanent loan when National Gallery officials learned that the Smithsonian was retrofitting its facilities with sprinklers. The Chief of the Fire Protection Division of the Smithsonian and a museum director met with National Gallery curators. As a result, the National Gallery now will lend art to sprinklered museums. There are still a few museums, however, that will not.

In 1990, in Chicago, a $75 million loss occurred in two buildings being renovated that housed nine art galleries. The loss of artwork amounted to $50 million. Fire doors had been removed from connecting openings. The building in which the fire started had been sprinklered, but the system was out of service pending the installation of a new system.

The valuable exhibits in one Canadian museum are protected by sprinklers, but for some reason the lounge and gift shop are not. Fire in the contents of the latter areas could generate enough smoke to seriously damage the exhibit area. The heat from a fire in the lounge and gift shop might set off sprinklers, yet the water would not be hitting any fire. Such "economy" or "selective placement" of sprinklers is "penny wise and pound foolish."

Perhaps the most visible opposition to sprinklers has been over the recent national model code requirement for sprinklers in one- and two-family homes. While sprinklers have been installed in many cities in the western United States for decades, the new regulations adopted in the rest of the country have been met with stiff opposition from home builders at the local and state levels of government. In some cases, home builders have been able to block sprinkler legislation or have enacted legislation repealed. The builders' primary complaint? The systems cost too much and will put home affordability out of the reach of many prospective homeowners.

Popular Misconceptions About Sprinklers

Fears arise out of some of the many misconceptions about sprinklers.

The Sprinkler System Will Discharge on Even a Trifling Fire

This is not true. In fact, it takes a sizable fire to activate a conventional sprinkler. In some cases, the sprinklers should be supplemented with other fire protection measures. If the fuel for the triggering fire happens to be valuable artwork, a serious loss may take place in the first few minutes. For example, valuable original prints of birds by John James Audubon are displayed in a sprinklered wooden house in Key West, Florida—but the amount of fire needed to trip the sprinklers already would have caused extensive damage to the collection by the time the sprinklers came on.

The Entire Building Will Be Drowned When the Sprinklers Go Off

In ordinary systems, the sprinklers go off one at a time, not all at once. Only in deluge systems do all the sprinklers discharge at once. Television perpetuates this myth. Only sprinklers on which heat is impinging will activate.

Water Does More Damage Than Fire

This is not true. There is no "water damage" at a total loss. Wet materials ranging from books to computers have been successfully salvaged. In contrast, heat-damaged or burned material is destroyed. In 1960, the fleet aircraft carrier USS *Constellation* suffered a devastating fire. Many computers that had been soaked with salt water and subjected to freezing for months were recovered; burned and heat-damaged computers were not. The major damage in many of today's fires is caused by the greasy, often corrosive smoke from burning plastic.

It is often recommended that laboratories be equipped with sprinklers. Some laboratory scientists have a great fear of water damage and endorse CO extinguishing systems as a panacea. Opposition to sprinklers can be overcome by pointing out that sprinklers provide academic freedom—the opportunity to attempt something dangerous without causing a disaster.

A prominent fire protection engineering firm designed a sprinkler system for a nuclear laboratory with 1/4" (6.4 mm) sprinklers (strainers had to be provided in the lines) to satisfy the fears of scientists about water damage. The water discharge was calculated to be just enough for the existing fire load. No controls existed to prevent the typical buildup of fire load, however. Such a system could be characterized as a "tinkler" system, designed only to annoy the fire.

This is not the case. At times the efficiency of sprinklers is deceiving. Consider the operation of one sprinkler that extinguishes a fire. The amount of burned material is relatively small. If the sprinkler flowed 15 minutes—a reasonable amount of time—about 500 gallons (1893 L) of water would be dumped. The observer concerned about water damage has no idea of what might have happened had the fire continued to burn.

The Pipes Might Leak

This is unlikely. Sprinkler piping is hydrostatically tested after installation for 2 hours at 200 psi (pounds per square inch)—much more extensive testing than domestic piping is subjected to. Sprinkler leakage losses are minor and are often due to careless use of lift trucks or freezing. If sprinklers are undesirable due to fear of possible leakage, then logically *all* plumbing should be eliminated. A properly installed sprinkler system is supervised, and an alarm will sound and the fire department will respond when water flows. No such alarm is provided on domestic piping.

Smoke Is the Big Killer So Smoke Detectors Are Better Than Sprinklers

A smoke detector does nothing to suppress the fire that is generating the toxic smoke; instead, the sprinklers suppress the fire and the production of smoke. However, sprinklers are slow to operate on a smoldering fire that is generating toxic gas. Smoke detectors are necessary for life safety and provide early warning, especially in sleeping occupancies, even though the sprinklers will control the fire as soon as it breaks out.

There have been tests of smoldering fires in which temperatures generated by the fire were too low for sprinkler activation, yet lethal concentrations of CO gas were produced. The concentrations developed over several hours, but potential victims in such situations may be disabled or disoriented before a fatal dose is received.

The NFPA has no record of a multiple-death fire (i.e., a fire that kills three or more people) in a completely sprinklered building where the system was properly operating. The only exception to this record exists in an explosion or flash fire or where fire fighters or plant employees were killed during fire suppression operations.

We Have Smoke Detectors and the Fire Department Is Right Down the Block

The fire department may be working at another incident. Patrick E. Phillips, chairperson of more than one NFPA fire alarm committee, has repeatedly warned that fire protection and fire detection are not synonymous. Only if the fire alarm is received where there is someone ready, willing, and able to control the fire could detection be considered to be protection. Many fires spread so fast that even immediate detection and response are ineffective. The myth that there are 15 minutes available to control a fire should be laid to rest. Consider this sad repudiation of this myth: a full-box alarm assignment of the Boston Fire Department was only a short distance away from the Cocoanut Grove Night Club where 492 people died in 1942.

Sprinklers Cause Damage to Libraries

Some librarians are opposed to sprinklers, citing a number of arguments against their use: the water will wash the classification labels off the backs of the books, water will damage the books, books are hard to burn, or we've never had a fire before.

For firefighting purposes, the major concern is not the local branch library, but rather the main library with its extensive and often irreplaceable collections.

The 1986 Los Angeles City Library fire is a case in point (Figure 6-20). This massive concrete structure was built in 1926. A concrete fort enclosed book stacks and racks for book storage. Upward ventilation was provided throughout the stacks to prevent mildew. It would be hard to imagine a better built-to-burn design. Not only did the design extend the fire, but the open construction permitted water to flow down to books below. The arsonist ignited the fire at the top of the stacks. The manual firefighting effort required 1,250,000 gallons of water. The cost of the fire loss was about $20 million. By contrast, the initial fire could have been controlled or extinguished by operating no more than two or three sprinklers.

The solution is full automatic sprinkler protection. Unfortunately, library stacks are perfectly arranged for spreading fire. They are simply racks storing combustible material without fire separation between levels. Ventilation is almost impossible—spaces are very constricted and passages are tight and tortuous. The heat produced in such a fire is extreme.

Figure 6-20 The Los Angeles City Library fire of 1986.

A number of municipal libraries are now sprinklered. An architect planning a new library asked the then Assistant Director of the Salt Lake City Library (Frank Brannigan's daughter Eileen), "What do you like most about your library?" Her reply shocked him, "It's sprinklered." She went on to explain that libraries are public buildings, making libraries vulnerable to arson. With the sprinklers in place, a disturbed person with a grievance can't destroy the library. As much as 85% of recent library fires were due to arson.

Smoke Detectors Set Off All the Sprinklers

A television show showed a cigarette setting off a smoke alarm, which in turn set off all the sprinklers in a building. The network has reportedly defended such misrepresentations by claiming "creative license." If someone advances this as a fact, it might be useful to mention that it was probably seen on a fictional TV show and is therefore fiction.

In addition, all fire department personnel should be alerted to the potentially serious damage caused by comments to the media made by uninformed occupants or careless remarks by fire fighters. The fireground commander should make it a point to explain to reporters the success of the sprinkler operation, if that is the case. Providing accurate information about sprinklers should go a long way toward dispelling the myths surrounding them and enhancing their acceptance.

Fire Service Activities to Correct Erroneous Opinions About Sprinklers

In years past, the sprinkler industry did little or nothing to overcome negative public perceptions. Promotion of the use of sprinklers was left to the public fire protection forces and the insurance industry. The Home Fire Sprinkler Coalition has worked to increase the knowledge to all sectors related to residential sprinkler systems.

Sprinkler Demonstrations

Some simple demonstrations have been useful in correcting erroneous opinions. Many mobile sprinkler demonstrators have been built to show the lifesaving efficiency of quick-response sprinklers. Conversely, some technicians in laboratory and computer occupancies are concerned that sprinklers will go off in a minor fire. To demonstrate the amount of fire it takes for a standard sprinkler to operate, consider the following demonstrations.

Attach a sprinkler to a length of steel pipe fed by a garden hose. Build a sizeable bonfire of fast-burning fuel. Hold the sprinkler over the fire. The sprinkler will be extremely slow to activate. Many who feared that the sprinkler would operate on a trifling fire will be amazed and converted.

Sprinklers and Flammable Liquids

(7 people believe that sprinklers will be totally ineffective on flammable liquids. At the Norfolk Naval Base, a demonstration was used to show that sprinklers would control the fire and make it possible for employees to get close enough for a fire extinguisher attack.

Fire Service Misconceptions About Sprinklers

The Building Is Sprinklered; There Is No Problem

Sprinklers are not a universal remedy for all fire problems. Inspectors have noted the presence of ceilings of burlap and other high-flame spread materials—a hazard that should not be dismissed lightly because "it's sprinklered." It is very doubtful that the sprinklers would operate in time to control the flame spread. Put simply, if a life hazard is so severe that it cannot be controlled by sprinklers, then the hazard should not be permitted to exist or other protection measures must be in place.

Supplying the Fire Department Connection Is a Secondary Operation

The sprinkler system should be backed up by fire fi rs as soon as possible after the responders' arrival. The more water a sprinkler discharges, the more heat that is absorbed. The supply pressure should be the maximum safe pressure because the increased density of the water pattern may be crucial. Some sprinkler systems have a higher working pressure than others. Preplans should include a statement as to the pressure to be supplied and maintained. The 1991 fire in the Meridian Building in Philadelphia was stopped by seven sprinklers on the 30th floor. It was estimated that the discharge from these sprinklers was three to four times the normal amount due to the pressure supplied by the fire department. It is possible that the sprinklers could have stopped the fierce fire attack if they were operating at only normal pressure.

Sprinklers Should Be Shut Down As Soon As Possible to Prevent Excessive Water Damage or to Clear the Air

Factory Mutual statistics show 23 fires in 10 years with losses of $43 million (1986 dollars) in which premature closing of valves by fire fighters was a major factor in exacerbating the damage. When a sprinkler system is controlling a fire, cooled gases are often driven downward and obscure vision. Sprinklers should not be shut off as long as hot water is falling down. All visible fire should be extinguished. The fire fighter who shuts a valve should be in full personal protective clothing with a radio and should remain at the valve so it can be opened instantly if needed.

Residential Sprinkler Systems Are the Same as Other Sprinkler Systems

Residential sprinklers, as defined by NFPA 13R, *Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies*, and NFPA 13D, *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes*, are not the same as sprinkler systems used in other structures. Residential sprinkler systems are intended to limit flashover and to hold a contents fire until the occupants can escape. There have been a significant number of successes with these systems **Figure 6-21**.

Residential structures, however, are only partially sprinklered under these standards. To make the

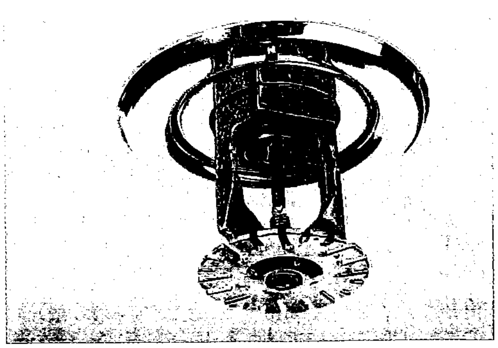


Figure 6-21 A residential sprinkler.

systems affordable while maintaining life safety, sprinklers are omitted from certain areas in residences. This is particularly significant when a residential sprinkler system is used in a multiple-family dwelling with truss floors or in a building with interconnected voids such as in rehabilitated buildings with lowered ceilings.

Some object to the term *partial sprinkler system*. They argue that this term should be applied to systems where sprinklers are omitted from areas vulnerable to fire. NFPA 13R and 13D systems are based on data that indicates the omitted areas are not vulnerable to fire. Unsprinklered areas include small closets and bathrooms as well as unused attics.

It is possible that data relevant to the combustible truss void that exists in truss floor buildings was not available at the time when NFPA 13R and NFPA 13D were developed; this lack of evidence in the database might explain the omission of this concern from the standards. It is a fact that fires originate in void spaces that would be unprotected by sprinklers. Electrical fires and failures of metal fireplace flues are but two possible causes of fires. Years ago, a number of the fires investigated at the NBS (today known as NIST) started in or very early extended into void spaces, which would be unsprinklered under NFPA Standards 13D and 13R.

The following few cases are representative of other fires that started or developed in areas that were unsprinklered or would be unsprinklered—and thus unaffected by sprinklers—under the standards cited:

- *Williamsburg, Virginia:* A "sprinklered" renovated dormitory at the College of William and Mary was destroyed by a void fire.
- *Syracuse, New York:* Although not a "void" fire, four fire fighters lost their lives in a fire in a fraternity house that had been equipped with a corridor sprinkler system for life safety.
- *De Kalb County, Georgia:* Fire resulting from a plumber's propane torch developed in the truss void of a nearly completed three-story apartment house with no contents load. The sprinkler system was operational, but the sprinklers didn't fuse. A fire fighter fell through the second floor into the fire when the truss collapsed. Fortunately, his partner used a hose line to protect him from the fire until he could be pulled out.
- *Orlando, Florida:* Fire started in a defective ceiling light fixture in a first-floor apartment of an unsprinklered three-story, brick-veneered, plywood-sheathed, truss-floor apartment house. The fire extended to upper floors on the outside of the wood sheathing, concealed by the brick veneer. The truss floor of the third floor sagged more than 1 foot.
- *San Antonio, Texas:* A spilled flammable liquid ran down into the truss void of an unsprinklered apartment house and was accidentally ignited. Fire fighters had barely complied with orders to get out when the floors collapsed.
- *Lake Benbrook, Texas:* An outside rubbish fire extended through the exterior wall into the truss void of an unsprinklered townhouse.

In plain language, the sprinkler systems in many buildings are partial sprinkler systems. This labeling is not meant to denigrate the usefulness of sprinklers in saving the lives of occupants and protecting property. As stated, there have been many successful sprinkler operations. Balancing the potential structural failures with the positive life safety benefits, Frank Brannigan was strongly in favor of the partial systems—in fact, his house was partially sprinklered in 1962. However, fire departments should not expect to receive the level of structural protection performance from residential sprinkler systems that they are accustomed to receiving from standard sprinkler systems.

The Fire Department and Sprinklers

In 1898, the International Association of Fire Chiefs resolved to have nothing to do with the practice of pumping into the newfangled invention called the automatic sprinkler. Today, the situation is entirely different: fire chiefs are enthusiastic supporters of automatic sprinklers. Some fire departments, however, seem to act as if "sprinklers are none of their business."

In the past, some insurance companies exhibited exactly the reverse attitude. That is, until high-rack warehouses presented a new problem, insurance companies, relying heavily on sprinkler protec- seemed to operate as if the fire department did not exist. For instance, Norman Thompson (then Director of Research for Factory Mutual) wrote a very important book, *Automatic Sprinklers*, published in 1951 by the NFPA, which led to the adoption of the then-new spray-type "standard sprinkler." The book makes no reference to the fire department supporting the sprinkler system. In a list of 20 things to do when fire occurs in the plant, the last item was "call the fire department."

There is no doubt that a properly designed, adequately supplied and properly inspected, tested, and maintained sprinkler system can almost guarantee that a fire will not destroy a building and will save lives. To "sell" sprinkler protection, however, concessions may be made with respect to other fire protection features, such as exit travel distances, flammability of surface finishes, size of fire areas, protection of void spaces, and other time-proven fire protection and life safety features.

It was noted earlier that almost all fire protection emphasis today is being placed on sprinklers, with the responsibility for them left with fire departments. The buildings department remains out of the picture after the Certificate of Occupancy is issued. The fire de- 'ment or fire prevention bureau then assumes the responsibility to ensure the system is operating properly after the building is built. The insurance company often compensates for its risks by raising the premiums or refusing to renew the risk.

Because sprinkler protection is so important, the fire department's responsibility cannot be permitted to end when the sprinklers are installed and approved. Fire fighters making fire suppression, preplanning, or fire prevention inspections should be acutely aware of the conditions that can cause sprinkler failure.

The fire department should take action when notified of a sprinkler system that is out of service or has other impairments. As part of monitoring its coverage area, it should keep up-to-date on systems being installed or that are temporarily out of service. When a sprinkler system is pronounced "out of service," the degree of impairment should be given. For example:

- The system can be supplied through fire department connections (FDC).
- Mechanics on scene can restore the system in 10 minutes.
- The system is completely unavailable.
- The second floor is out of service.

In Cartaret, New Jersey, a fire in the S&A Plastics plant severely exposed a Unocal storage facility containing hundreds of drums of flammable solvents. This building, in turn, exposed a number of tanks. Fire Superintendent Richard Greenburg had reviewed the plans for a sprinkler system being installed in the drum storage building. He had the system supplied through the FDC and, assisted by a Unocal employee, opened the valves. Fourteen sprinklers checked the spread of the fire. Five sprinklers had opened before the water was turned on, demonstrating that the potential for a disastrous extension was real.

Why Were the Sprinklers Installed?

As you have seen, there are several reasons for installing sprinklers. The nature of the reason may help to determine fire department action concerning impairments. The model building and fire codes permit a number of trade-offs (often resulting in cost reductions) when sprinklers are installed. For instance, there can be a greater travel distance to exits and narrower exit components than what is required in an unsprinklered building. This provides substantial savings in the building of a shopping mall, for example.

What action should the fire department take when it learns that the sprinkler system is out of service in a department store, a shopping mall, or any structure with a population of thousands? The life safety of all the occupants depends almost totally on adequate sprinkler protection. Use the fire code provisions that allow for the implementation of a fire watch.

There have been several fires in unsprinklered department stores with a heavy loss of life. Over 100 Christmas shoppers and employees died in the Taiyo Department Store in Kumamoto, Japan, in 1973. Sprinklers were being installed in the new addition of the store that was under construction, but the law did not apply to the existing structure.

The fire department action should be the same as if a large proportion of the exits were blocked. In such a case, the fire department would have no hesitation in shutting down the store until the condition was corrected. This doesn't mean that many stores would have to be shut down. When the alternatives are properly explained to management before the crisis arises, the work can be done while the store is closed.

A fire department that does not accept the scenario, or doesn't plan to take any action when sprinklers installed for life safety are shut down, would be well advised to send the following inquiry to the city attorney:

> Dear Counselor:
>
> Consider a building in which building code modifications, particularly reduction in egress requirements, were permitted because the building was sprinklered. What is our legal position if we were notified that the sprinklers were turned off while the building was occupied, no special action was taken in such a case, a loss of life occurred during a fire, or a key factor in loss of life was that the victims could not get out in time?
>
> In addition to legal action against the city, is it reasonable to expect that senior officers could be sued successfully?
>
> Sincerely,
>
> Fire Chief

The legal situation may vary depending upon why the system was installed, so the fire department should identify the reason why each sprinkler system was installed. If the sprinkler system was installed for life safety or in accordance with another code provision, there still may be a legal responsibility to take action if the sprinklers are out of service. Even if there were no legal requirement for the installation of sprinklers, the loss of the sprinklers may create such a serious situation that the fire department can act under general legal provisions authorizing the abatement of serious hazards.

All too often, an old building of ordinary construction with sprinklers shut down or removed could produce a disastrous fire that destroys or threatens to destroy adjacent structures. For example, in 1983, a spectacular fire in Donaldson's Department Store did $90 million damage to the adjacent fire-resistive high-rise of the Northwestern State Bank in Minneapolis, Minnesota.

Fire Department Policy

The fire department should have a formal policy on the subject of sprinkler systems out of service. The policy should be reviewed and approved by the governing authority, making it a legal requirement. The policy should cover items such as the following:

- *Fire department notification:* It may be necessary to seek the cooperation of other licensing authorities to place the burden of notifying the fire department directly on the sprinkler contractor