CHAPTER C2

FIRE PROTECTION SYSTEMS PIPING

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INTRODUCTION

General

Fire protection systems are unique in that the majority of their service life is spent in a static, no-flow condition. However, when required to operate in an emergency, fire protection systems can be critically important to the safety of building occupants, the protection of property, and the continued operation of a facility. For these reasons, the piping associated with fire protection systems must be designed to minimize service interruptions and be capable of operating reliably over an extended period of time.

To ensure that fire protection systems are reliable, building and insurance authorities require that they be constructed in accordance with nationally recognized standards. Federal regulations or locally adopted requirements may also be applicable.

Fire protection piping, as treated in this chapter, deals with the network of distribution piping that delivers fire extinguishing agents. This chapter presents general information on piping materials, available references, and design considerations for both aboveground system piping and underground water supply piping.

Types of Fire Suppression Systems

There are numerous types of fire suppression systems. All of them use piping or tubing to convey fire suppression agents to a protected area or to a specific fire hazard. The type of fire suppression system selected for a particular building or location depends on the nature of the fire hazard, the value of the building and contents, applicable code and regulatory requirements, and physical considerations such as environment and aesthetics. The common fire suppression systems are described in the following subsections.

Automatic Sprinkler Systems. An automatic sprinkler system, for fire protection purposes, is a network of piping to which automatic sprinklers or open sprinklers are attached. The system is connected to an automatic water supply. The piping network and connected sprinklers are distributed throughout the protected area in accordance with fire protection engineering standards.

Automatic sprinkler systems may be wet pipe, dry pipe, preaction, or deluge type (each discussed independently in the following paragraphs) depending upon the conditions by which water is admitted into the piping for distribution out of the sprinklers. With the exception of the deluge-type system, which uses open sprinklers, all automatic sprinkler systems use automatic sprinklers.

Automatic sprinklers are sealed by a heat-responsive element such as a eutectic solder link or a frangible glass bulb. When the heat-responsive element of an automatic sprinkler reaches its predetermined operating temperature during a fire, the individual sprinkler opens, discharging water to control the fire.

System operation is generally stopped manually by closing the system control valve. Control valves should be kept in the open position until the fire is completely extinguished and should be constantly manned during postfire overhaul operations in case the fire rekindles.

The *wet pipe* system is the most basic and common type of automatic sprinkler system. See Fig. C2.1. It is the most economical system as well as the most reliable one due to its simplicity. In the wet pipe system, the system piping is constantly charged with water under pressure. In addition to the *main control valve*, the system may also have *sectional control valves*. The system is also required to include at least a local water flow alarm. It is now common to use central station signaling systems to monitor water flow in the system; to supervise the open position of system control valves; and to supervise the ready condition of water supply elements such as pumps, pressure tanks, and gravity tanks.

The *water flow alarm* device for any automatic sprinkler system is located in the main supply pipe of the system, generally a vertical section of main termed the *system riser*. For a wet pipe system the alarm device is usually either an alarm check valve or a paddle-type water flow switch. An *alarm check valve* (see Fig. C2.2) is a valve with a free-swinging, hinged clapper that opens when water flows through the system and automatically reseats when the flow stops. Moving the clapper from its seat, as in a system flow condition, opens ports that permit water to flow to mechanical water gongs or electric pressure switches. In a *water flow switch,* (Fig. C2.3) the paddle in the water piping lies motionless until water flows through the system. Movement of the paddle by water flow closes contacts used to initiate electrical alarms.

Automatic wet pipe sprinkler systems are provided for general fire suppression throughout an area where fixed suppression is required and where there are no special considerations that restrict their use.

Dry pipe automatic sprinkler systems are used primarily in unheated occupancies and structures. See Fig. C2.4. In a dry pipe system, a *dry pipe valve* is located in the main supply header or system riser. All piping downstream of the dry pipe valve is charged with air or nitrogen to hold the clapper of the dry pipe valve closed. The dry valve is configured to give a mechanical advantage to the downstream pressure, such that 30 to 40 psi (200 to 300 kPa) air or nitrogen pressure can hold back up to 175 psi (1200 kPa) water pressure. When a sprinkler opens, the air or nitrogen is released, tripping the dry pipe valve and introducing water to the system piping. See Fig. C2.5.

Deluge systems are used to provide fire protection specifically for high-hazard equipment or areas such as transformer areas and ammunition magazines. A deluge

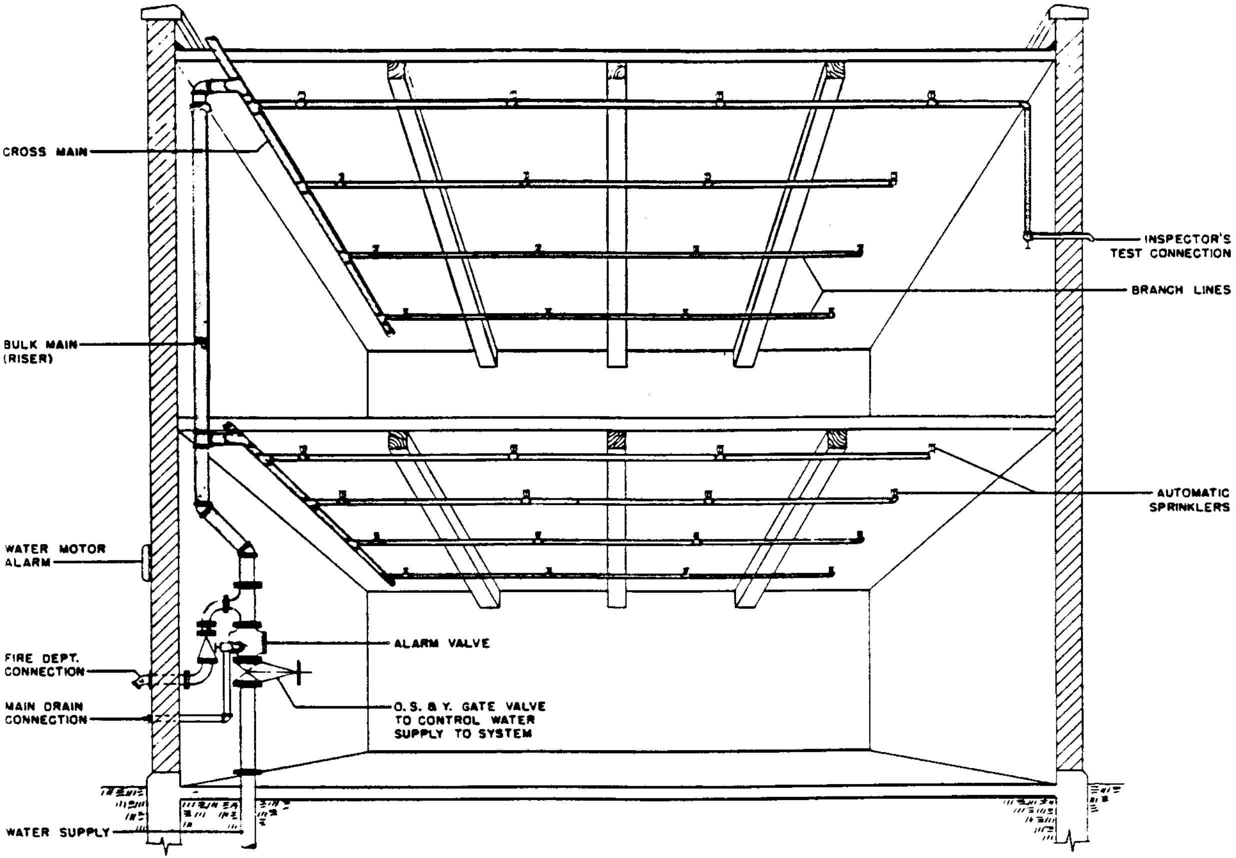

FIGURE C2.1 Typical wet pipe system.

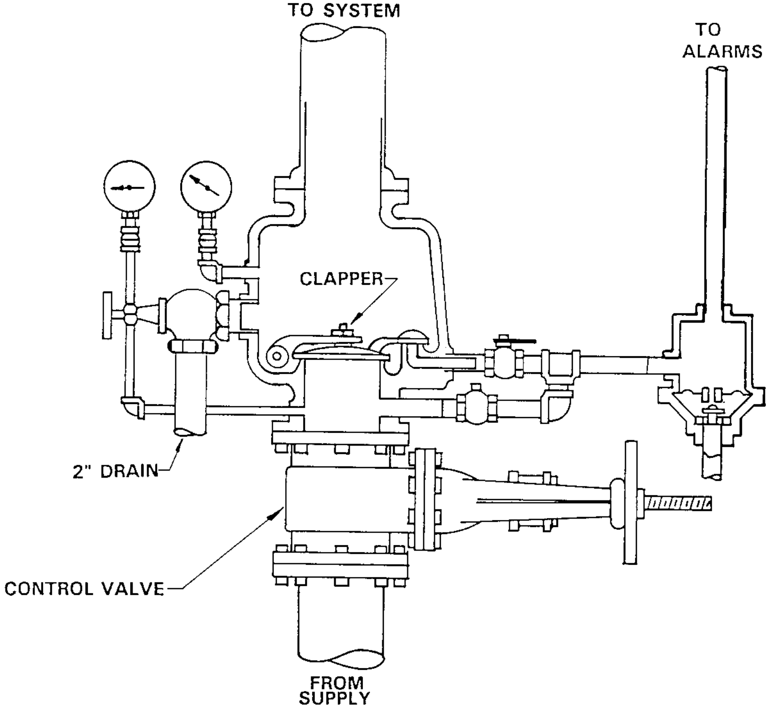

FIGURE C2.2 Typical wet pipe system alarm check valve.

valve, as described for the preaction system, is provided in the main supply header or system riser. See Fig. C2.6. A *deluge valve* is a normally closed, automatic control valve located in the system riser that prevents water from entering the system piping until required. Operation of the deluge valve is achieved by an electric, hydraulic, or pneumatic signal initiated by a separate detection system located within the protected space. The detection system can employ fixed temperature or rate-of-rise heat detectors, smoke detectors, infrared or ultraviolet detectors, or separate ‘‘pilot line’’ sprinklers. The deluge valve must also be arranged to be operated manually. Open sprinklers or spray nozzles are mounted to the piping network of deluge systems in lieu of sealed automatic sprinklers. When the deluge valve is opened upon activation of the separate detection system, water simultaneously flows from all sprinklers or spray nozzles on the system.

Preaction sprinkler systems are provided for fixed fire suppression where it is particularly important to prevent the accidental discharge of water into an area. The piping network of a preaction sprinkler system is maintained dry until water is needed for fire suppression. Automatic sprinklers are installed on the piping network. See Fig. C2.7.

A deluge valve is provided for each preaction system. The preaction system is generally required to be charged with a low supervisory air pressure.

Preaction systems can be configured in various ways. The traditional preaction system, in which water enters the piping based only upon the activation of the

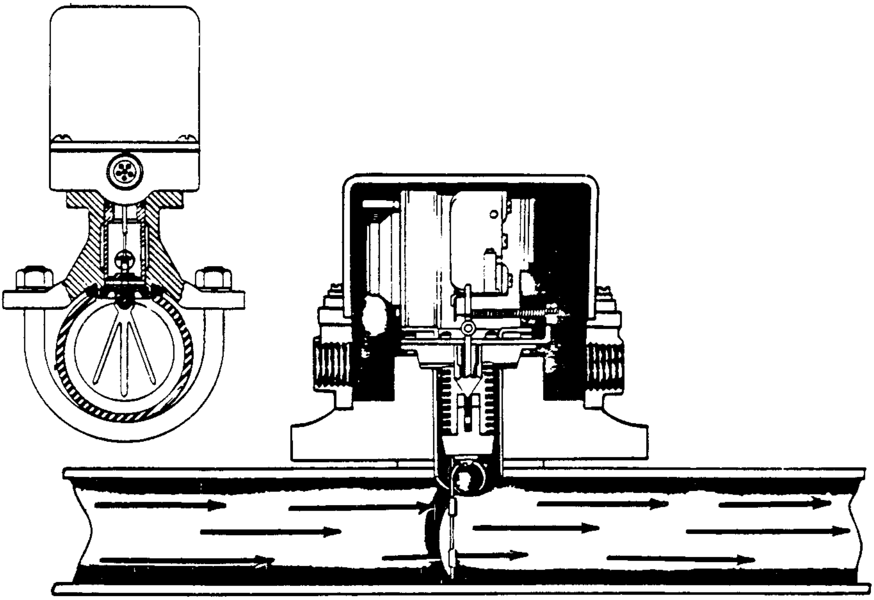

FIGURE C2.3 Water flow detector/switch.

detection system, is now termed a *single-interlock* preaction system. A *noninterlocking* preaction system is one configured such that either the activation of the detection system or the operation of an automatic sprinkler permits water to flow into the system piping. A *double-interlock* preaction system, intended for use in freezers and other locations where water trapped in the piping would cause damage, requires both the activation of the detection system and the operation of one or more automatic sprinklers in order to release water into the system piping.

Gaseous Fire Suppression Systems. Gaseous fire suppression systems are provided in areas where water is not the extinguishing agent of choice, such as for specialized electronic equipment rooms or water-sensitive storage areas. Nevertheless, it is often recommended that gaseous fire suppression systems be supplemented with an automatic sprinkler system protecting the same area due to the high reliability of the latter.

Gaseous fire suppression systems formerly included *halogenated gas* (Halon) suppression systems, but these have been largely eliminated by international agreement due to their ozone-depleting properties. New alternative ‘‘clean agents’’ have joined carbon dioxide as acceptable gaseous fire suppression system agents. These extinguishing agents are generally stored in pressurized cylinders or tanks. The number of cylinders and quantity of extinguishing agent required for a particular area is dependent on the volume of the protected space, the design concentration demonstrated to achieve fire control or extinguishment, and the physical arrangement of system piping and nozzles.

Automatic activation of these systems is initiated by an electrical signal from a

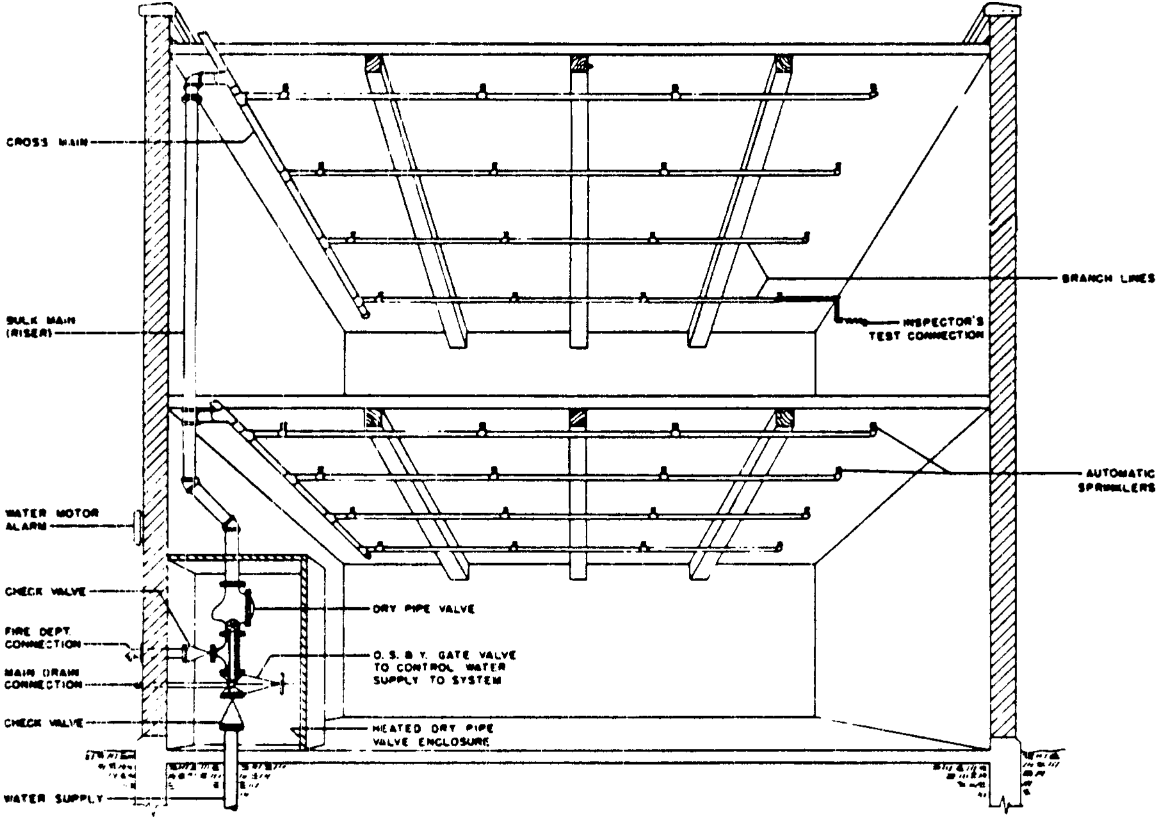

FIGURE C2.4 Typical dry pipe system.

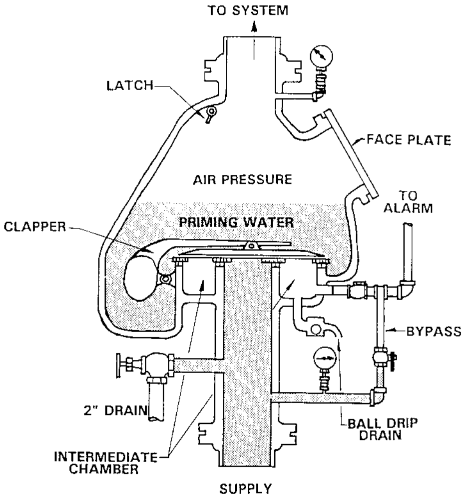

FIGURE C2.5 Schematic dry pipe valve diagram.

separate detection system installed in the protected space. When the detection system senses the fire condition, the extinguishing agent is released into the protected space. Manual means for discharging the systems are also provided. Discharge of gases that would create a hazard to life safety must be accompanied by warning systems within and around the protected area.

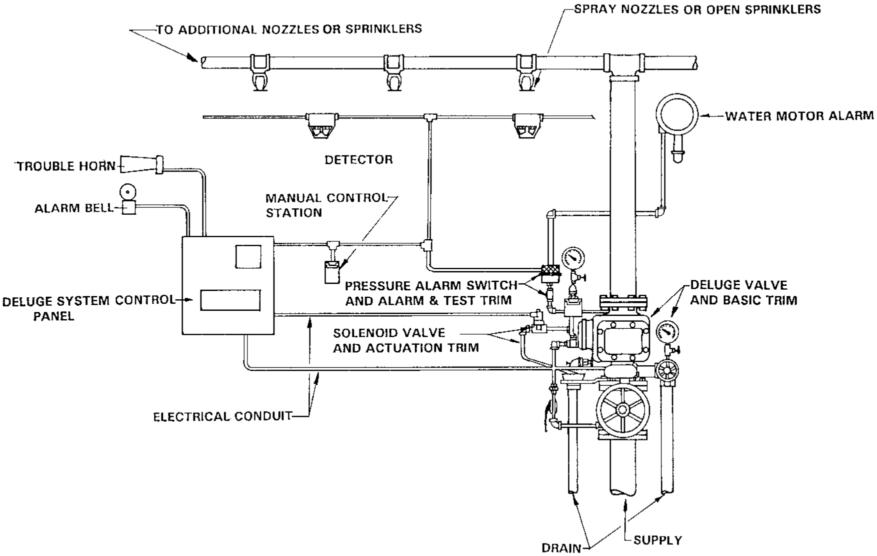

FIGURE C2.6 Typical deluge system diagram.

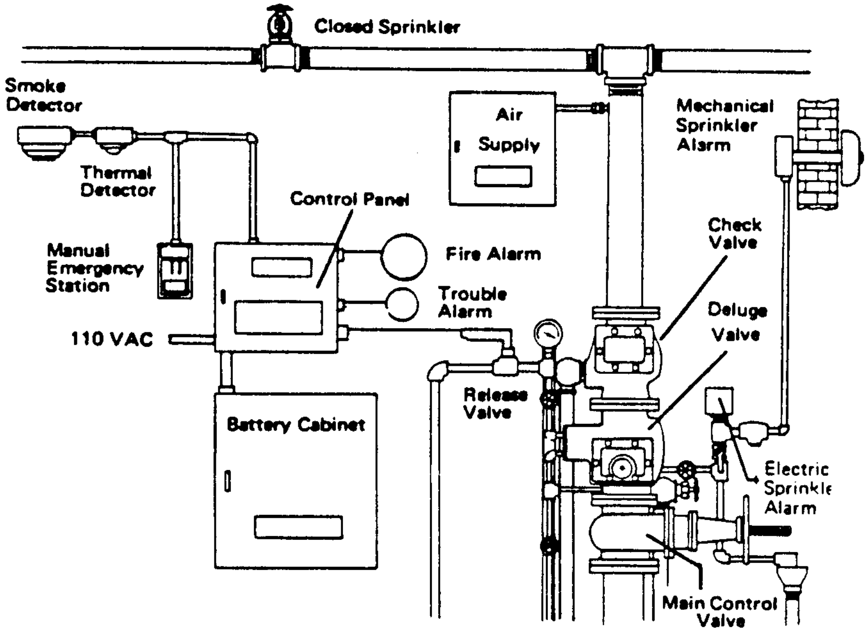

FIGURE C2.7 Typical preaction sprinkler system diagram.

To be effective, the extinguishing agent must be maintained in the protected area at design concentrations for a sufficient length of time, often 10 minutes or more. To maintain the concentration level, the protected space should have boundary penetrations appropriately sealed to prevent leakage of the agent.

Foam Fire Suppression Systems. Foam fire suppression systems are used primarily to protect hazards or areas having flammable liquid fire hazards. The fire extinguishing foam is made by mixing foam concentrate and water within the piping network. The foam extinguishes fire by smothering the fire, suppressing flammable vapor production, and cooling the fuel in adjacent areas.

The specifications for piping material that carries foam concentrate and solution must be closely coordinated with the recommendations of the foam manufacturer. Often stainless steel piping is recommended. Selecting an inappropriate piping material may increase maintenance needs on the system and decrease the piping's usable service life.

Foam can also be added to automatic sprinkler systems to improve performance, especially for fires involving flammable liquids.

Chemical Extinguishing Systems. Dry and wet chemical extinguishing systems are generally *preengineered* systems, meaning that flow rates, nozzle pressures, and quantities of agent are predetermined for the geometries of specific hazards.

Historically, the most common application for these systems has been for restaurant, commercial, and institutional hoods, plenums, and ducts, mainly those associated with cooking appliances. *Dry chemical* systems employ a powder composed of very small particles, usually with a base of either sodium bicarbonate, potassium bicarbonate, or ammonium phosphate. *Wet chemical* systems employ a solution of water and either potassium carbonate-based or potassium acetate-based chemicals.

Water Mist Systems. Water mist systems were developed in part to substitute for the use of Halon, and in part as an alternative to the use of automatic sprinkler systems where water supply must be kept to a minimum due to limitations on either weight or volume. Water mist systems are distinguished from automatic sprinkler systems by their smaller droplet sizes, which tend to be more effective in cooling but less effective in penetrating upward fire plumes. Some water mist systems are configured much like automatic sprinkler systems, utilizing small orifices to produce the small droplet diameters. Others utilize pressures in excess of 1500 psi (10 MPa) to produce the water mist. Still others employ twin fluid nozzles, using air or nitrogen under pressure to break a water stream up into a fine mist.

Standpipe Systems. A standpipe system consists of a network of piping that supplies water for manual fire suppression throughout a building or facility. The network is supplied by a fire protection water supply system and it distributes water to normally closed standpipe valve outlets or hose stations.

Standpipe systems often serve as the source of water supply to automatic fire sprinkler systems, particularly in high-rise buildings. In such cases, sprinkler systems on each floor are fed from the vertical standpipe riser through floor control valves. Each floor is provided with a water flow switch and a combination test/drain valve, connected to a separate drain riser. This enables the alarms from the flow switches on each floor to be tested.

Hydrant Systems and Water Supplies. Hydrant systems are generally used in conjunction with private fire service mains, which also serve to distribute water from the source of supply to most water-based fire protection systems. In many cases the source of supply is the public water main as maintained by the public water works company. In other instances, such as in a large industrial plant, the water supply system may be privately owned and operated. Regardless of ownership, the design of the water supply to fire protection systems is a critical factor in assuring reliable fire protection.

A fire protection water supply system may consist of storage tanks, pumps, underground and aboveground piping, and associated control and isolation valves. Underground valves are normally of the post indicating type.

The capacity and pressure required of a particular water supply system is generally related to the design demands of the water-based fire suppression system in conjunction with the normal water consumption for a facility. Additionally, local authorities and insurance organizations often prescribe fire flow requirements for individual properties.

REFERENCE DOCUMENTS

Codes and Standards

As a rule, building and fire codes do not specifically address fire protection system piping, but instead reference system installation standards. The generally recognized standards that address fire protection systems piping are those developed by the National Fire Protection Association (NFPA). Federal regulations may reference applicable NFPA standards, but often include special requirements for unique fire protection systems such as those protecting marine, military, or nuclear facilities. Local, municipal, or state regulations may also be applicable.

Some insurance organizations publish their own standards or supplements to the NFPA standards that may be applicable to a particular project.

Some generally recognized standards that relate to fire protection piping systems are listed in Table C2.1. Table C2.2 contains additional standards referenced with regard to materials, joining and installation methods.

There are additional NFPA codes, standards, and recommended practices and guides which may contain specific design criteria for particular hazards or facilities. A complete listing of available documents developed by NFPA technical committees is available by contacting the National Fire Protection Association, Batterymarch Park, P.O. Box 9101, Quincy, MA 02269–9101.

Fire protection standards often require specific equipment or materials to be ''listed.'' The term *listed* means that the equipment or material has been evaluated by a recognized product evaluation organization and has been found to meet appropriate standards or has been tested and evaluated for use in a particular fire protection application. Recognized organizations concerned with product evaluation publish lists of evaluated and approved, i.e., listed products. Additionally, the listing organization performs periodic follow-up inspections of the production of listed

TABLE C2.1 National Fire Protection Association (NFPA) System Standards

NFPA standard no.	Title
NFPA 13	Standard for the Installation of Sprinklers
NFPA 13D	Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Mobile Homes
NFPA 13R	Standard for the Installation of Sprinkler Systems in Residential Occupancies Up to Four Stories in Height
NFPA 14	Standard for the Installation of Standpipe and Hose Systems
NFPA 20	Standard for the Installation of Centrifugal Fire Pumps
NFPA 22	Standard for the Installation of Water Tanks for Private Fire Protection
NFPA 24	Standard for Private Fire Service Mains and Their Appurtenances
NFPA 11	Standard for Low-Expansion Foam
NFPA 11A	Standard for Medium- and High-Expansion Foam Systems
NFPA 15	Standard for Water Spray Fixed Systems
NFPA 16	Standard for Deluge Foam-Water Sprinkler and Spray Systems
NFPA 16A	Standard for the Installation of Closed-Head Foam-Water Sprinkler Systems
NFPA 231	Standard for General Storage
NFPA 231C	Standard for Sprinkler Protection for Rack Storage of Materials
NFPA 12	Standard on Carbon Dioxide Extinguishing Systems
NFPA 12A	Standard on Halon 1301 Fire Extinguishing Systems
NFPA 17	Standard for Dry Chemical Extinguishing Systems
NFPA 17A	Standard on Wet Chemical Extinguishing Systems
NFPA 750	Standard on Water Mist Fire Protection Systems
NFPA 1963	Screw Threads and Gaskets for Fire Hose Connections
NFPA 2001	Standard on Clean Agent Fire Extinguishing Systems

TABLE C2.2 Additional Standards for Fire Protection Piping

ASME B36.10M	Welded and Seamless Wrought Steel Pipe
ASME B36.19M	Stainless Steel Pipe
ASME B1.20.1	Pipe Threads, General Purpose
ASME B16.18	Cast Copper Alloy Solder Joint Pressure Fittings
ASME B16.22	Wrought Copper and Copper Alloy Solder Joint Pressure Fittings
ANSI/AWWA A21.50/C150	Thickness Design of Ductile-Iron Pipe
ANSI/AWWA A21.51/C151	Ductile-Iron Pipe, Centrifugally Cast, for Water or Other Liquids
ASME B31.1	Power Piping Code
ASME B31.3	Process Piping Code
ASTM A795	Black and Hot-Dipped Zinc Coated (Galvanized) Welded and Seamless Steel Pipe for Fire Protection Service
ASTM A53	Welded and Seamless Steel Pipe
ASTM A135	Electric Resistance Welded Steel Pipe
ASTM A268	Seamless and Ferretic Stainless Steel Tubing for General Service
ASTM A269	Seamless and Welded Austenitic Stainless Steel Tubing for General Service
ASTM A632	Seamless and Welded Austenitic Stainless Steel Tubing (Small Diameter) for General Service
ASTM A778	Welded Unannealed Austenitic Stainless Steel Tubular Products
ASTM A789/A789M	Seamless and Welded Ferritic/Austenitic Stainless Steel Tubing for General Service
AWWA C203	Standard for Coal-Tar Protective Coatings and for Steel Water Pipelines—Enamel and Tape—Hot Applied
AWWA C205	Standard for Cement/Mortar Protective Lining and Coating for Steel Water Pipe [4 in (100 mm) and Larger]—Shop-Applied
NFPA 51B	Standard for Fire Prevention in Use of Cutting and Welding Processes

equipment and material. It is important that all fire protection piping products be used in applications consistent with their listing.

For fire suppression system equipment, two product evaluation organizations in the United States are generally recognized by authorities having jurisdiction as providing appropriate listing services: Underwriters Laboratories, Inc. (UL) and Factory Mutual Research Corporation (FM).

Other Reference Documents

Other references related to the design of fire protection piping systems include the following:

- NFPA Fire Protection Handbook, National Fire Protection Association
- Fire Protection Equipment List, Underwriters Laboratories, Inc.
- Factory Mutual System Approval Guide, A Guide to Equipment, Materials and Services Approved by Factory Mutual Research for Property Conservation

- Automatic Sprinkler Systems Handbook, National Fire Protection Association
- The SFPE Handbook for Fire Protection Engineering, Society of Fire Protection Engineers
- AWWA Handbooks, Manuals and Standards, American Water Works Association
- Federal Regulations, Standards and Specifications
- State and Local Codes and Standards
- Insurance Organization Standards and Manuals

Federal agencies and departments that regulate fire-protection-related matters reference NFPA standards extensively. However, specific federal regulations may be issued. When issued for enforcement, these federal regulations are published in the Code of Federal Regulations, available from the General Services Administration. Departments of the U.S. Government that issue regulations related to fire protection include the General Services Administration; the departments of Defense, Energy, Labor, Veterans Affairs, and Housing and Urban Development; and the U.S. Coast Guard and branches of the military.

Several insurance organizations publish standards to be used in the evaluation of property insurance risks and to provide fire protection guidance to their insureds. Such organizations include the Factory Mutual Research Corporation (FMRC), Industrial Risk Insurers (IRI), and Kemper Insurance. The Insurance Services Office (ISO) relies exclusively on the use of NFPA standards. Other insurance associations that exist for special underwriting risks such as the nuclear, marine, textile, and food industries sometimes have their own guidelines and special requirements.

Most standards related to fire protection piping have been developed based on the needs and experience of a particular region or industry. In North America, these standards are generally based on NFPA codes and standards. With the increasing global community and economy, awareness of standards from other countries and communities is becoming imperative. Examples include DIN (German Standards Institute), AFNOR (French Standards Association), and BSI (British Standards Institute). It should be recognized that many European standards are currently being harmonized as CE (European Community) standards.

DESIGN CONSIDERATIONS

To ensure that all necessary aspects that could impact fire protection piping systems are considered, design goals should be established based on present and projected system needs and conditions. These design goals must consider expected fire suppression system demands, building locations, economic constraints, reliability, water supply source availability, design pressures, and environmental conditions.

Design Conditions

Working Pressure. The maximum working pressure of a particular installation must be considered when selecting the type and class of pipe to be used. To determine the maximum working pressure for water systems, designers should consider fire pump shut-off head, elevation changes, and the expected range of source pressures.

Pipe in underground fire service mains is generally expected to withstand a working pressure of not less than 150 psi (1.0 MPa). System components are listed accordingly.

Pipe in overhead fire protection systems such as sprinkler systems and standpipe systems is generally listed for a minimum working pressure of 175 psi (1.2 MPa). This matches the usual minimum working pressure of system components such as automatic sprinklers, water flow switches, alarm valves, and dry valves. However, some components are listed for higher working pressures. When working pressures exceeding 175 psi (1.2 MPa) are expected, all valves, fittings, and pipe should be rated for the appropriate pressure. Several types of pipe specifically listed for fire protection service are listed for a working pressure of 300 psi (2.0 MPa).

Because sprinkler system components are generally intended for use up to 175 psi (1.2 MPa), higher pressures should be avoided. However, in design situations such as high-rise buildings and large multibuilding complexes, higher pressures may be necessary. When these situations occur, sprinkler system components should be protected from excessive pressures. This is accomplished by utilizing approved pressure-reducing valves.

Pressure-reducing valves are intended to protect components from both high static (nonflowing) and flowing pressures. A pressure relief valve that simply drains away flow to relieve pressure is not a pressure-reducing valve, nor is a restricting orifice that simply reduces flowing pressures. A *pressure control valve* is a pilot-operated pressure-reducing valve that can be used to reduce the downstream water pressure to a maximum specific value under both static and flowing water conditions. The setting of the valve must be carefully controlled and its operability regularly maintained to assure that sufficient pressure is available to properly operate the fire protection systems.

When evaluating the impact of fire pump operating pressures on the maximum working pressure conditions, the total discharge pressure at pump shut-off should be considered. Centrifugal fire pumps, the types of pumps used in most water-based fire protection systems, are permitted to have a shut-off or churn pressure of up to 140 percent of rated pressure.

The minimum operating pressure at the discharge point of sprinklers or spray nozzles must be maintained to assure proper discharge flow and water spray distribution. Operating below these minimums can prevent a system from controlling or suppressing a fire.

NFPA 13 requires a minimum discharge operating pressure of 7 psi (48 kPa) for any sprinkler. Higher minimums are required for devices with special applications or nonstandard coverage areas and flows, such as extended-coverage sprinklers. The minimum pressure required for such specific application sprinklers can be unique to manufacturer, model, and intended application. These higher minimums are part of the sprinkler's listing and are described in the manufacturer's product literature that is approved at the time of the product listing.

The working pressures for gaseous suppression systems and water mist can be substantially higher than those normally found in most water-based fire protection water systems. Storage cylinders with pressures of 600 to 850 psi (4 to 6 MPa) are typical for gaseous systems, and pressures in excess of 1500 psi (10 MPa) are encountered with some types of water mist systems. These pressures result in substantial thrust forces and piping stresses that are critical factors in the design of these fire suppression piping systems.

Sources of Water Supply. Water for fire protection purposes can be obtained from public water systems, storage tanks, and raw water sources such as rivers, lakes, and reservoirs. The source must be reliable and of sufficient flow and capacity to operate the connected fire protection systems.

The required flow capacity and residual pressure for a particular building is dependent on automatic sprinkler system demand, hose stream demand for interior fire fighting purposes, and exterior hose stream demand from fire hydrants. The required flow capacity at minimum residual pressure is often referred to as the *system demand*. For a sprinkler system, system demand is the minimum water supply required to operate the number of sprinklers contemplated to open from a particular fire hazard, plus an allowance for manual hose stream operations. NFPA 13 covers water supply requirements for most automatic sprinkler systems.

NFPA 14 provides requirements for the water supply necessary for various classes of standpipe systems. For fully sprinklered buildings, the water supply for sprinklers need not be added to the standpipe system demand required by NFPA 14. This is in recognition of the reduced likelihood of a large uncontrolled fire in a fully sprinklered building. For partially sprinklered buildings, the sum of the sprinkler system demand and standpipe system demand must be supplied by the water source.

Water demand requirements for a particular building in excess of minimum standards may be set forth by the loss-prevention department of the property's insurance carrier.

When raw water is the supply source for automatic sprinkler systems, special provisions are required to reduce the accumulation of sediment in piping drop nipples. Return bends are required to prevent the accumulation of sediments in drop nipples that might eventually plug sprinklers, obstructing the flow of water (see Fig. C2.8).

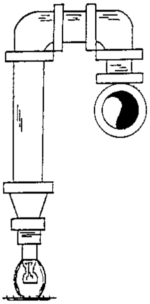

FIGURE C2.8 Typical return bend arrangement.

All sprinkler system cross mains must be arranged for flushing with easily removable fittings. Internal inspections of fire protection piping systems should be conducted whenever any of the following conditions are observed:

- Defective intake screens for fire pumps taking suction from open bodies of water
- Discharge of obstructive material during system tests
- Foreign material in fire pumps or system valves
- Plugged sprinklers, nozzles, or piping during system alterations
- Failure to flush yard piping or surrounding public mains at time of new installation or repairs
- Record of broken public mains in the vicinity
- Abnormally frequent false tripping of dry pipe valve(s)
- System returned to service after shutdown exceeding a year
- Reason to suspect sodium silicate or highly corrosive fluxes were used within system piping

Freezing Temperatures. Fire protection piping systems must be protected from freezing when temperatures cannot be constantly maintained above 40°F (4°C). For underground mains, burying pipes below the frost line is the usual method to protect against freezing. The depth of cover for underground water mains to avoid freezing in different regions of the United States and Canada is shown in Fig. C2.9.

In fire protection system piping, there may be no circulation of water through the piping such as exists in a public waterworks system. As such, depth of bury is usually deeper than with other piping systems. Exposed short sections of pipe should be boxed or wrapped and heated, since the use of exterior insulation only on exposed pipes is likely to be ineffective for prolonged exposure to freezing condition.

Aboveground fire protection systems must also be protected from low temperatures. Where required, this is usually accomplished by providing special suppression systems such as a dry pipe sprinkler system. For dry pipe systems, the dry pipe valve must be located within a heated enclosure. Attempts to use heat tape to protect dry valve bodies against freezing can result in damage to internal gaskets and seals.

For residential sprinkler systems, where the pipe is separated from the heated area by no more than a sheet of gypsum board, R-19 insulation carefully installed between the system piping and the exterior walls and roof is considered capable of protecting the pipe from exterior temperatures as low as −40°F (−40°C). This assumes that the building interior is maintained at a minimum 50°F (10°C) temperature. Insulation should never be used between the sprinkler system piping and the heated space.

Corrosive Environments. Corrosive conditions, both in soil and in air, require special precautions for fire protection system piping, fittings, and hangers. The

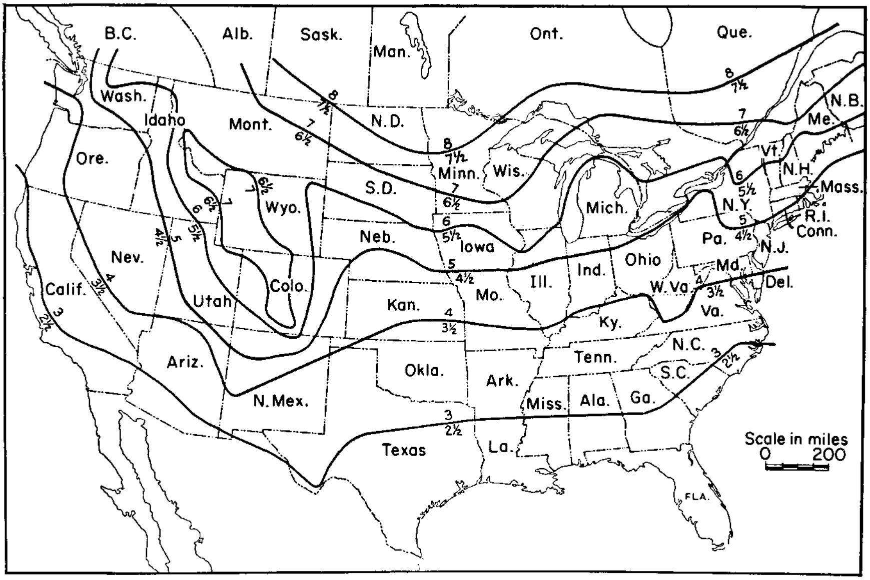

FIGURE C2.9 Depth of cover (in feet) map.

precautions may involve the use of corrosion-resistant material or the application of protective coatings or wraps. The method of protection depends on the expected severity of the corrosive conditions.

All buried ferrous metal pipe be lined, and steel pipe must be coated and wrapped to meet the requirements of NFPA 24. Galvanizing, either internally or externally, does not satisfy these requirements. Buried steel pipe fittings must also be lined, and fittings and joints must be field-coated and wrapped after assembly.

Cement mortar lining should be in accordance with the requirements of AWWA C104 for ductile iron pipe and fittings, of AWWA C205 for steel water pipe, or of AWWA C602 when lining pipe in place. Polyethylene encasement in accordance with AWWA C105 is recognized for protecting ductile iron pipe. When coal-tar enamel protective coatings are used for steel water pipe, the requirements of AWWA C203 apply. AWWA C105 is referenced for polyethylene encasement of steel pipe as well.

Damage to piping due to corrosive atmospheric conditions can be a problem in areas with high levels of moisture, salt air, or fumes from corrosive chemicals. Where these conditions exist, corrosion-resistant pipe, fittings, and hangers should be used or a protective coating applied to exposed surfaces. In high-moisture areas, consideration should be given to the use of galvanized pipe or copper tubing for aboveground fire protection piping. Commercial grade corrosion-resistant paint can be used in a corrosive environment. As with any coating, maintenance is important for maximum effectiveness.

When a corrosive water supply exists, threaded thin-wall pipe should be avoided. When these conditions exist, piping wall thickness should be at least Schedule 40. NPS 8 (DN 200) and larger pipe may be Schedule 30.

Seismic Integrity. Fire protection piping systems require protection from damage when installed in areas subject to earthquakes. Areas where the potential for earthquake damage exists and special protection is required are determined by building codes, insurance requirements, and regulatory agencies.

Where earthquake protection is required for aboveground piping, NFPA 13 provides appropriate design criteria for automatic sprinkler systems and similar systems. NFPA 13 does not require seismic protection, but rather provides criteria where such protection is required by other codes and standards. Flexible pipe couplings, lateral and longitudinal sway bracing, and prescribed pipe clearances are strategically used to prevent damage to piping.

Flexible mechanical pipe couplings are mandated at strategic points in the system where building components are expected to move differentially. For example, flexible couplings are required near the top and bottom of sprinkler and standpipe risers on each floor of multistory buildings to accommodate maximum expected building drift. Except where flexible couplings are provided on both sides of walls, floors, platforms, and foundations, annular clearances up to 2 inches (50 mm) are necessary. Sway bracing is used to limit excessive lateral and longitudinal movement of mains and large branch lines where the system is expected to move with the building, such as below floor/ceiling slabs.

NFPA 13 provides additional details on the seismic protection of sprinkler systems. Alternate means of protecting automatic sprinkler systems from earthquake damage to those found in NFPA 13 may be used when an analysis demonstrates that acceptable system performance is achieved under expected seismic forces. For additional information on piping system stress analysis and supports, refer to Chaps. B.4 and B.5 of this handbook.

Aboveground Piping

Materials and Wall Thickness. Fire protection piping systems can convey many different suppression agents at a wide range of operating conditions. These agents include water and aqueous solutions, chemicals, and gases, each with different piping material requirements. Therefore, aboveground piping for fire protection systems must be designed and installed in accordance with the applicable NFPA standards relating to the system type being installed. The appropriate type of pipe is determined by design considerations, economics, ease of installation, and trouble-free service and environmental factors.

The vast majority of piping used in aboveground piping for fire protection is steel, which accounts for more than 90 percent of installations. Steel piping for fire sprinkler systems and most other water-based fire suppression systems must either be listed for its service or meet or exceed the requirements of one of the following specifications:

ASTM A795—Black and Hot-Dipped Zinc Coated (Galvanized) Welded and Seamless Steel Pipe for Fire Protection Service

ASTM A53—Welded and Seamless Steel Pipe

ASTM A135—Electric-Resistance Welded Steel Pipe

ASME B36.10M—Welded and Seamless Wrought Steel Pipe

Out of concern for potential clogging of small orifices, water mist systems are not permitted to be constructed of black steel or galvanized piping. Piping is required to have corrosion resistance equivalent to pipe made to the following acceptable standards:

ASTM A269—Seamless and Welded Austenitic Stainless Steel Tubing for General Service

ASTM A632—Seamless and Welded Austenitic Stainless Steel Tubing (Small-Diameter) for General Service

ASTM A778—Welded Unannealed Austenitic Stainless Steel Tubular Products

ASTM A789/A789M—Seamless and Welded Ferritic/Austenitic Stainless Steel Tubing for General Service

NFPA 13 provides wall thickness requirements for steel pipe in sprinkler systems. The wall thicknesses are dependent on pipe size and the method of joining. Heavier wall pipe is required when threaded fittings or cut groove mechanical fittings are used. Refer to Table C2.3.

TABLE C2.3 Sprinkler System Minimum Nominal Wall Thickness, Steel Pipe (ASTM A795, A53, A135) for Pressures up to 300 PSI

	Pipe diameter		
Fitting type	Up to NPS 5 (DN 125)	NPS 6 (DN 150)	NPS 8 (DN 200) and larger
Welded	Sch. 10	0.134 in (3.4 mm)	0.188 in (4.8 mm)
Roll grooved	Sch. 40	0.134 in (3.4 mm)	0.188 in (4.8 mm)
Threaded	Sch. 40	Sch. 40	Sch. 30
Cut grooved	Sch. 40	Sch. 40	Sch. 30

Nearly half of all steel piping used in sprinkler systems today is threaded, with the other half generally roll-grooved or welded. Only a small percentage utilizes cut grooves or other joining techniques. Yet only about half of the threaded pipe conforms to the wall thicknesses shown in Table C2.3. This is because NFPA 13, since the late 1970s, has also permitted other types and thicknesses of pipe to be used for sprinkler systems when the product has been evaluated and listed for fire protection service and installed per manufacturer's instructions.

The original special listed steel pipe was threadable lightwall pipe, with wall thicknesses approximating Schedule 10, but with tolerances tightly controlled such that the outside diameters were held to the low end of the allowable range. This permitted the maximum remaining wall thickness at the most vulnerable point in the piping system: the first exposed thread outside of the fitting. Even so, the remaining wall thickness at that point was substantially less than that of threaded Schedule 40 pipe. Underwriters Laboratories, the product evaluation organization that granted the first listing, developed a mechanism by which to evaluate the severity of the reduced wall thickness. The corrosion resistance ratio (CRR) was calculated for each type and size of pipe as the cube of the ratio of remaining wall thickness compared to that of Schedule 40 pipe in the same nominal diameter:

$$\mathrm{CRR} = (t/t_{40})^3 \tag{C2.1}$$

where t is the least wall thickness of the special listed pipe (at the first exposed thread root for threaded pipe) and t_{40} is the wall thickness at the first exposed thread root for Schedule 40 pipe of the same nominal pipe size.

The CRR values for various sizes of threadable lightwall pipe vary from as little as 0.18 to 0.35. Because the rate of pitting corrosion through the wall is believed to progress at a rate comparable to the cube of the wall thickness, these CRR values would indicate a life expectancy of 18 to 35 percent of comparable Schedule 40 steel pipe. The actual life expectancy needed depends on site-specific conditions related to the corrosivity of the water supply and other environmental factors.

Threadable lightwall products now account for almost a third of the threadable pipe installed in fire protection systems. But the fastest growing segment of the threadable steel sprinkler pipe market is made up of listed threadable alternates to Schedule 40. Like the threadable lightwall, they are manufactured with tightly controlled tolerances. However, their nominal wall thickness is closer to that of Schedule 30, so as to produce a first exposed thread root that permits a CRR value of 1.0, equivalent to Schedule 40 pipe.

Special listings are also being obtained for high-strength thinwall pipe for use in automatic sprinkler systems. Between Schedule 5 and Schedule 10 in nominal wall thickness, these products must be joined by roll-groove fittings or welding.

Gaseous suppression systems are often subject to higher operating pressures than water-based suppression systems. Additionally, thrust forces are a major consideration in the acceptability of piping and fittings. For gaseous systems, ferrous piping must be black or galvanized steel pipe conforming to either ASTM A53, Grade A or B or ASTM A106, Grade A, B, or C. Other piping materials appropriate for high pressures, such as stainless steel and copper, may be used for gaseous systems. When these are used, pipe wall thickness must be calculated per the Power Piping Code, ASME B31.1. Refer to Chapter B2 in Part B of the handbook. NFPA Standards do not permit the use of ordinary cast-iron or nonmetallic piping for gaseous suppression systems.

Copper tubing for water-based fire suppression systems must meet or exceed the requirements of ASTM B75 or ASTM B88. Copper tube used in sprinkler systems must have a wall thickness of Type K, L, or M. Bending of copper tube (Types K and L) is acceptable per NFPA 13, which specifies a minimum bend radius of 6 pipe diameters for NPS 2 (DN 50) and smaller pipe, and 5 pipe diameters for NPS 2-½ (DN 65) and larger pipe.

Several of the NFPA standards permit the use of other types of pipe and tube in aboveground piping systems if they are investigated and listed by recognized testing organizations for fire protection service. When used, the pipes must be installed in accordance with the limitations of the organization's listing, including all installation instructions.

When other pipe materials are investigated for use by a testing laboratory, many factors are considered. These include:

- Working pressure rating
- Beam strength affecting hanger spacing requirements
- Unsupported vertical stability
- Movement during sprinkler operation affecting sprinkler or nozzle distribution
- Corrosion resistance, both internal and external
- Resistance to failure when exposed to elevated temperatures
- Joining methods (strength, permanence, and fire resistance)
- Integrity during earthquakes

Special thermoplastic piping systems have been investigated and have been approved for use in some fire suppression system installations—specifically residential and other light hazard automatic sprinkler and water mist systems. The thermoplastic piping material that is currently listed is chlorinated polyvinyl chloride (CPVC). Not all CPVC pipe that is manufactured is acceptable for use in fire sprinkler systems. Only pipe that is specifically approved for fire protection service and that carries the listing mark of a nationally recognized independent testing laboratory such as Underwriters Laboratories, Inc. may be used. The basic standard used by UL to evaluate thermoplastic sprinkler pipe is UL 1821—Thermoplastic Sprinkler Pipe and Fittings for Fire Protection Service. Polyethylene piping is currently being investigated for use in residential sprinkler systems.

Special installation and design criteria exist for listed nonmetallic fire suppression piping systems. These criteria are contained in the listing information for the material and relate to:

- Limitations on use based on hazard classification
- Physical protection and pipe location
- Hanger spacing
- Piping restraint and deflection
- Maximum ambient temperature

Piping Joints. There are several acceptable means of joining aboveground fire protection piping. Steel pipe with sufficient wall thickness may be joined using *threaded connections*. See Table C2.3. Threads must be cut to the requirements of ASME B1.20.1, Pipe Threads, General Purpose.

In normal applications, threaded fittings which have been listed for use in fire suppression systems by a recognized testing laboratory may be used with steel pipe with wall thicknesses less than Schedule 40 for pipe sizes NPS 8 (DN 200) and smaller, and Schedule 30 for sizes NPS 8 (DN 200) or larger.

Sections of aboveground fire protection piping may be *shop-welded*. However, field welding of fire protection piping should be avoided. When it is necessary to cut or weld inside a building, strict fire prevention precautions as described in NFPA 51B must be established at the site.

Welding methods for joining fire protection pipe are described in the NFPA standard for the type of suppression system being installed. Welding methods that comply with AWS D10.9, Level AR-3 or Section IX of the ASME Boiler and Pressure Vessel Code are generally acceptable.

Mechanical couplings have become a popular method of joining aboveground fire suppression system piping. Mechanical couplings are assemblies of clamps, gaskets, and bolts. There are mechanical couplings appropriate for use on rolled groove, cut groove, and plain pipe ends. Refer to Chap. A9 of this handbook.

Couplings for rolled groove pipe may be used with pipe having a minimum wall thickness of Schedule 10 unless specifically evaluated and listed for use with for thinner wall pipe. Since cut grooved pipe reduces wall thickness similar to threads, fittings for cut grooved pipe are limited to Schedule 40 pipe in sizes less than NPS 8 (DN 200). Schedule 30 may be used in pipe sizes NPS 8 (DN 200) and larger with cut grooved mechanical fittings. Only mechanical couplings which have been investigated and listed by a recognized testing laboratory specifically for fire protection service may be used. Working pressures, temperatures, system rigidity needs, and external and internal loads should always be investigated when considering mechanical joining methods. Many styles of mechanically joined piping components are available including couplings, fittings, and valves.

Listed pipe couplings and fittings can be either flexible or rigid. *Flexible couplings and fittings* are defined as those that permit axial displacement, rotation, and at least 1 degree of angular movement of the pipe without inducing harm on the pipe. For pipe sizes NPS 8 (DN 200) and larger, angular movement is permitted to be less than 1 degree, but not less than 0.5 degree. *Rigid-type pipe couplings* are those that do not permit sufficient flexibility to meet the noted criteria.

Plain-end pipe fittings are popular for sprinkler system installation due to the lack of needed pipe-end treatment. When used, they must be listed and be used with pipe having a minimum wall thickness specified by the manufacturer's installation instructions.

Only mechanical couplings which have been investigated and approved by a regular testing laboratory specifically for fire protection service may be used. Working pressure, temperatures, system rigidity needs, and external and internal loads should always be investigated when considering mechanical joining methods. Many styles of mechanically joined piping components are available including couplings, fittings, and valves.

In general, copper tubing used in fire protection systems should be joined by brazing in accordance with the requirements of ASME B16.22. However, soldered joints may permitted for wet pipe systems protecting Light and Ordinary Hazard Occupancies when the maximum ceiling temperature is less than 150°F (65°C) and the tube is concealed. Where soldering is used, the fittings shall conform to the requirements of ASME B16.18.

Nonmetallic fire protection piping system components are joined using methods and materials that have been evaluated by the listing organization. A solvent cement is used for CPVC pipe. The methods and restrictions for joining nonmetallic pipe materials are detailed in manufacturer's installation instructions. These instructions are included as part of the product's special listing by the testing organization that evaluated and listed the product. Nonmetallic materials are prohibited for gaseous systems.

Due to the more extreme operating pressures and thrust forces associated with gaseous suppression systems, fittings capable of withstanding higher pressures are required. ANSI C.S.P. (carbon steel pipe) Class 150 and cast iron fittings are not permitted. For example, fittings for 600 psi (4 MPa) stored pressure Halon 1301 systems are required to have a working pressure of 100 psi (690 kPa). Due to the cooling effect that gaseous system discharges have on the piping system, the relationship between material temperature and coincident pressure rating must be considered. For additional guidance, refer to ASME B31.1 and manufacturer information.

Hangers and Supports. The adequate support of aboveground fire protection piping systems is important. NFPA standards provide detailed information on methods and rules of proper support of sprinkler system piping. Other standards commonly reference NFPA 13 regarding hangers and supports.

Aboveground piping must be independently supported from the building structure. Hangers may not be suspended from ceilings or nonstructural partitions. The points of connection to the structure must be capable of supporting the sprinkler system.

Hanger components for aboveground piping systems are typically made of ferrous materials. Nonferrous hanger components may be used only when they have been evaluated as acceptable through fire testing and are listed by a recognized testing organization.

Hanger components that attach to the pipe or to the building structure (such as clamps, concrete inserts, and hanger rings) must be listed. If the hanger components are not listed, the hanger and installation methods must be designed to support five times the weight of the water-filled pipe plus 250 lb (114 kg) at each point of connection, in addition to any other applied loads at the point of hanging.

The maximum spacing between hangers is related to the piping's rigidity based on the piping material and the pipe size, in accordance with the requirements of the installation standards or the piping's listing. In general, hangers for steel pipe NPS 1-½ (DN 40) and larger can be spaced no more than 15 ft (4.6 m) apart. For steel pipe smaller than NPS 1-½ (DN 40), the maximum spacing is reduced to 12 ft (3.7 m).

Nonmetallic piping systems and some special listed steel piping systems require closer hanger and support spacing. The maximum support spacings are detailed in the product's installation instructions. For example, maximum hanger spacing for NPS 1 (DN 25) diameter UL-listed CPVC sprinkler piping is 6 ft (1.8 m), increasing to 10 ft (3.0 m) for NPS 3 (DN 80) diameter CPVC pipe. For discussion of nonmetallic piping, refer to Part D of the handbook.

Many different styles and types of hangers are available for use with the various types of ceiling construction. Careful evaluation of hanger alternatives will result in a well-supported and reliable piping system. For additional details on hangers and supports, refer to Chap. B5.

Piping Layout and Design. The piping layout for most aboveground fire protection piping systems consists of risers, feed and cross mains, and branch lines. *Branch lines* are the pipe sections to which the sprinklers or nozzles are attached. The *feed mains* and *cross mains* are the pipes which supply the branch lines. *Risers* are essentially vertical feed mains.

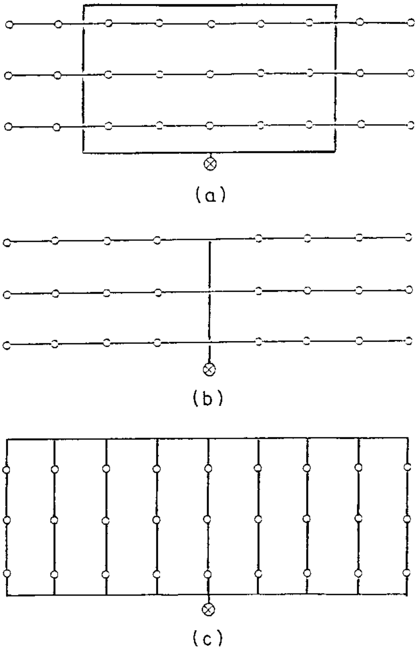

FIGURE C2.10 Typical sprinkler system piping layouts: (*a*) grid; (*b*) tree; (*c*) loop.

The piping layout should be carefully considered to ensure that the resulting arrangement conforms to applicable standards in a manner that provides maximum efficiency and flexibility.

Considerations should include the following:

- Proper location and size of risers
- Available water supply location and its characteristics
- Building construction, height, and area
- Hazard classification
- Interferences to piping layout, including overhead cranes, ducts, and so forth.
- Architectural considerations such as aesthetics

There are three basic piping layout configurations for sprinkler systems: tree, loop, and grid. See Fig. C2.10. The tree configuration is the traditional piping layout. Loop and grid layouts have become popular with the use of hydraulically designed systems.

Piping layout of aboveground fire protection piping associated with automatic sprinkler systems involves the following principles:

- Provide automatic sprinklers throughout
- Do not exceed the maximum permitted area of protection per sprinkler
- Position sprinklers to optimize activation and water distribution

The most effective automatic sprinkler system provides full area coverage throughout the protected premises. Partial systems are sometimes used to protect hazardous areas in an otherwise nonsprinklered facility. The use of partial systems should be considered with caution, as it is difficult to predict with accuracy where a fire is most likely to occur. Additionally, a partial sprinkler system may not be capable of controlling a fully developed fire spreading from a nonsprinklered area.

The maximum protection areas per standard sprinkler are shown in Table C2.4. Systems with nonstandard sprinklers may exceed these areas when designed and installed in accordance with the listing limitations of the extended coverage or specialized sprinklers.

Sprinklers should be postioned to optimize activation and distribution. The spacing of branch lines and the location of sprinklers relative to walls, ceilings, structural members, and other obstructions are important factors.

The layout of aboveground fire protection piping for gaseous systems differs significantly from that of sprinkler systems. Rather than sprinklers located at prescribed spacing throughout an area, the objective of gas system nozzle placement is to achieve design gas concentrations by strategic nozzle placement to assure

TABLE C2.4 Maximum Protection Area per Standard Sprinkler

Hazard classification	Ceiling construction	Maximum protection area
Standard pendent and upright sprinklers		
Light	Unobstructed or noncombustible obstructed	225 ft^2 (20.9 m^2)
	Combustible obstructed	168 ft^2 (15.6 m^2)
Ordinary	All	130 ft^2 (12.1 m^2)
Extra	All	100 ft^2 (9.3 m^2)
High-piled	All	100 ft^2 (9.3 m^2)
Standard sidewall sprinklers		
Light	Combustible finish	120 ft^2 (11.1 m^2)
	Noncombustible or limited combustible finish	196 ft^2 (18.2 m^2)
Ordinary	Combustible finish	80 ft^2 (7.4 m^2)
	Noncombustible or limited combustible finish	100 ft^2 (9.3 m^2)

proper distribution and mixing of the gas when discharged. Also, due to working pressures up to 850 psi (6 MPa) and high discharge velocities, the support of the piping layout is critical. For additional information, refer to NFPA 12A or 12B for Halon suppression systems and NFPA 13 for carbon dioxide suppression systems.

Inspection and Testing. Prior to making connections to aboveground piping risers, underground piping must be flushed to remove any accumulated sediment or material which could affect suppression system operation.

To assure adequate cleaning, the minimum flow rate for the flushing should achieve a velocity of 10 ft/s (3 m/s) in the underground piping system.

Newly installed pipe should be hydrostatically tested for leaks and to detect faulty pipe, fittings, or joints. No visible leakage is acceptable for interior fire protection piping. Aboveground fire protection piping should be tested at a minimum hydrostatic pressure of 200 psi (1.4 MPa) for two hours. If the maximum system pressures exceeds 150 psi (1.0 MPa), the hydrostatic test pressure should be 50 psi (350 kPa) greater than the maximum pressure. For example, if the maximum system pressure was 175 psi (1.2 MPa), the hydrostatic test pressure should be 225 psi (1.5 MPa) minimum.

Underground Piping

Materials. The selection of appropriate underground pipe and fittings for fire service mains should consider economical installation, trouble-free service, and easy maintenance. The review of these factors should include the required methods of trenching and laying, the characteristics of the water to be handled, and the corrosiveness of the soil. The pipe material should be recognized by applicable codes and standards, and be suitable for the conditions under which it will be installed.

The majority of pipe for underground fire service mains currently being installed is ductile iron. *Ductile iron* is a cast-iron material where the primary graphite content occurs as nodules or spheroids. The graphite in this form maximizes impact resistance and ductility.

Ductile iron pipe that is manufactured in accordance with ANSI/AWWA A21.51/C151 may be used for fire protection service. The pipe class, or wall thickness, required for a particular condition should be determined on the basis of expected internal pressure, laying conditions (e.g., trench load, vehicle loads), and soil characteristics.

Design methods for determining the minimum required thickness of ductile iron pipe are provided in ANSI/AWWA 21.50/C150. These methods consider the conditions of trench load and internal pressure. The net thickness required to withstand the larger of bending stress or deflection caused by the trench load is added to the thickness required for the hoop stress due to internal pressure. Additional thickness is provided to the sum of these net thicknesses for service allowance and casting tolerance.

As previously indicated, steel pipe is generally not permitted for underground fire mains. However, due to its high strength, it is sometimes used by special permission for locations subject to vibrations or shock as from railroad tracks, truck crossings, or highways. When used, steel pipe should conform to AWWA C200, be standard weight for the size (Schedule 40 minimum), and be lined and coated for corrosion protection.

Nonmetallic pipe is available for use in underground fire service mains. Nonmetallic materials used include polyvinyl chloride, reinforced concrete, and polyethylene and glass fiber reinforced composites. The benefits of these materials may include their light weight and corrosion resistance. When used for underground fire protection service, the pipe should be listed, comply with applicable standards, and be installed according to the manufacturer's installation instructions.

Joints. Joints for underground fire protection piping vary with piping material. The joint must be suitable for the pipe material, working pressures, and the particular installation conditions. Manufacturers specifications should be followed.

The majority of cast-iron and ductile iron joints are push-on or mechanical. Bell and spigot joints that use jute and molten lead are no longer used but are found in many existing installations.

Push-on joints utilize a special rubber gasket. The rubber gasket is placed in the bell end of the pipe. When the spigot end of the pipe is pushed into the socket past the gasket, the joint is formed. Push-on joints do not require packing or caulking. For more details on push-on type joints, refer to Chap. A2 in this handbook.

Mechanical joints are those which utilize a bolted follower ring or gland to hold the gasket in place. The ring is placed over the spigot end, and bolts are used to compress the gasket and the bell end of the pipe. The bolts must be tightened in accordance with the manufacturer's recommendations. They should also be coated to minimize corrosion. Refer to Chap. A2 and A7 in this handbook for additional information regarding this type of joint.

Joints for steel pipe may be welded, threaded, or mechanical. Welding should conform to AWWA C206, Standard for Field Welding of Steel Water Pipe Joints. Since field welding can damage pipe coatings and linings, the weld ends are left bare. Coating and lining are then applied to the welded joints area after welding is completed. Any damage should be repaired.

Nonmetallic pipe is joined using approved butt fusion, push-on joints, mechanical fittings, or solvent cement and couplings. The limits of the approval and the manufacturer's recommendations should be followed.

Installation. Many factors need to be considered when laying underground pipe, including preparation of the trench, placing and aligning the pipe, making the joints, and anchoring, leak testing, and backfilling the installation.

Trenches should be excavated carefully to minimize the potential for crumbling walls or cave-ins. In sandy or lose soils, sheeting or bracing may be necessary. The bottom of the trench should conform to the grade of the pipeline. It may be necessary to excavate to an extra depth and prepare a stable pipe bed with a layer of firmly compacted soil. Pipes should not be laid in contact with rocks or boulders.

The trench should be wide enough to allow careful alignment of the pipe and convenient making up of the joint. Space should be provided below joints so that the joint can be properly made and so that there will be no localized bearing load on the joint.

Foreign material and water should not be permitted to enter the pipe during installation. Unattended open pipe ends should be closed using watertight plugs or by other means. Additionally, flotation of pipe during installation due to excessive trench water should be avoided by using sufficient backfilling.

Most types of underground pipe joints are not designed to resist significant axial forces that would tend to pull them apart. The friction between the pipe and the ground will help to resist this lateral movement. However, where such forces are significant such as at bends, tees, plugs, and at points where pipe is laid with a steep slope, special consideration is required. A typical location where lateral restraint is required is at the connection of a fire service main to a fire protection system riser. See Fig. C2.11.

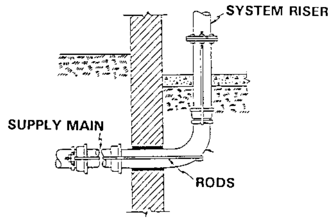

FIGURE C2.11 Typical fire protection riser restraint.

To restrict lateral movement, joints at bends, tees, and plugs should be anchored by clamps, rods, bolts, or concrete thrust-blocks. Mechanical fittings can be obtained with lugs for anchorage by tie-rods. Pipe clamps and anchor straps are also available.

When determining anchorage methods, consideration must be given to the maximum forces produced by water pressure, the direction in which the forces act, and allowances for favorable conditions such as pipe-to-earth friction and the resistance that can be provided by various anchorage methods.

Table C2.5 quantifies forces tending to separate single joints at such locations as plugs, tees, the base of hydrants, and bends having only one joint that needs

TABLE C2.5 Forces (in pounds) to be Resisted by Anchorage at Pipe Joints

Size, in.	Outside diam, in.	Separating force produced by 200 psi at tee and plug	Resultant of forces at bends		
			90 deg (1.41)	45 deg (0.765)	22½ deg (0.385)
6	6.90	7,500	10,600	5,740	2,890
8	9.05	12,900	18,200	9,880	4,970
10	11.10	19,400	27,400	14,850	7,480
12	13.20	27,300	38,200	20,850	10,520
14	16.65	38,400	54,200	29,400	14,800
16	17.80	49,700	70,100	38,000	19,150
20	22.96	76,400	108,000	58,400	29,450

anchorage; it also provides the resultant effect of the two forces acting at the ends of an elbow or bend.

As just indicated, thrust blocks may also be used to anchor horizontal pipes at fittings (see Fig. C2.12). For maximum effectiveness, thrust blocks should bear against undisturbed soil yet leaving the pipe joint accessible for inspection and repair. Thrust blocks should only be considered satisfactory where the bearing soil is suitable to provide support.

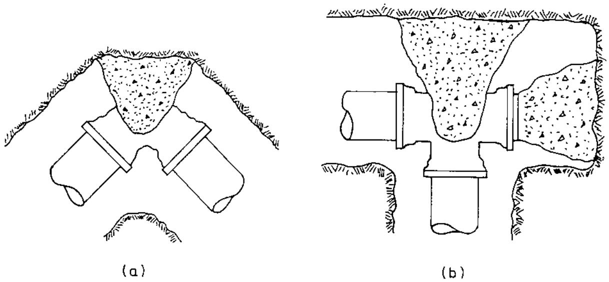

FIGURE C2.12 Typical thrust block configurations.

Thrust blocks should be made of concrete mixed not leaner than 1 part cement, 2½ parts sand, and 5 parts stone. The bearing area should ensure adequate resistance to the thrust force anticipated. NFPA 24 provides guidance on the required bearing area of concrete thrust blocks. The required bearing face area of concrete thrust blocks is dependent on the type of fitting being restrained (such as quarter-bend or tee), the system's water pressure, and the undisturbed soil resistance.

Coatings and linings are used for underground piping installations to resist the corrosiveness of water and soil. Protective coal tar enamel per AWWA C203 and cement-mortar coatings and linings (AWWA C205) are used extensively.

Polyethylene encasement, in accordance with AWWA C105, provides good protection to cast- and ductile iron pipe exposed to corrosive soil conditions. Cathodic protection systems may also be used for the external protection of iron and steel water mains against galvanic action.

The backfill for underground fire protection piping should be free of cinders, refuse, plant material, and rocks, and have a consistency that will compact firmly. The top of the piping shall be buried not less than 1 ft (0.3 m) below the frost line for the locality but in no case less than 2.5 ft (0.75 m) below the surface to prevent mechanical damage. The depth of cover for underground fire protection piping to avoid freezing in different regions of the United States and Canada is shown in Fig. C2.9. Due to variations in pipe material performance under varying temperature conditions, manufacturer's instructions should always be followed.

Inspections and Testing. Newly installed fire protection mains should be inspected for faulty pipe or fittings. The piping should be hydrostatically tested for tightness. Prior to hydrostatically testing newly installed underground pipe, the installation should be firmly backfilled to above the centerline of the pipe for cast- and ductile iron pipe. For nonmetallic pipe, the backfill should extend 1 to 2 ft (0.3 to 0.6 m) over the pipe, except at joints. All joints, regardless of pipe type, should be left exposed until tests are satisfactorily completed. If used, thrust-blocking should be adequately cured to restrict pipe movement.

Similar to aboveground fire protection piping, all new underground piping

TABLE C2.6 Typical Values for Hazen-Williams Formula

Type of pipe	Value of *C*
New or in condition of new, pipe	
Cast iron—unlined	120
Cast iron—cement lined	130
Cast iron—bituminous lined	140
Nonmetallic	140
Steel	140

should be hydostatically tested at not less than 200 psi (1.4 MPa) for 2 hours. If the service pressure and rating of the pipe installed exceeds 150 psi (1.0 MPa), the hydrostatic test pressure should be 50 psi (350 kPa) above the service pressure or rating.

An entire installation may be tested at once, or smaller sections may be tested using installed isolation valves. All entrapped air should be released from the test section using hydrants or connected aboveground fire suppression systems.

During the hydrostatic testing, all joints should be inspected for leakage. A small amount of leakage is permitted for new underground fire protection piping installations. The quantity of leakage is determined by pumping from a calibrated container. The maximum amount of leakage permitted by NFPA 24 for new pipe is 2 quarts per hour (1.89 l/h) per 100 gaskets or joints. The pipe diameter and the length of pipe gaskets are not considered. When a metal seated valve is used to isolate a test section, the allowable leakage is increased to compensate for valve leakage at a rate of 1 fluid ounce per inch of valve diameter per hour (30 ml/25 mm/h) for each metal seated valve isolating the test section.

Pipe Sizing

Most modern fire protection piping systems are hydraulically designed. That is, appropriate pipe sizes are determined by considering system demand, available water supply, and pipe network considerations such as friction loss, elevation changes, and pipe type.

TABLE C2.7 Variation in Hazen-Williams Coefficient *C* with Age of Unlined Cast-Iron Pipe

Age of pipe, years	Value of *C*
New	120
10	105
15	100
20	95
30	87
50	75

TABLE C2.8 Friction Loss in Pipes (f in Hazen-Williams Formula) Loss in pressure in psi per 1,000 ft of pipe $C = 100$*

Flow (gpm)†	Inside diameter of pipe (in) (nominal)‡						
	4	6	8	10	12	14	16
50	1.47	0.204					
60	2.06	0.285					
75	3.11	0.430					
100	5.29	0.735	0.181				
125	8.0	1.11	0.273				
150	12.1	1.55	0.381				
200	19.1	2.65	0.652	.0220			
250	28.8	4.00	0.985	0.332			
300	40.4	5.62	1.38	0.466	0.192		
400	68.8	9.55	2.35	0.793	0.326	0.154	
500	104.0	14.4	3.53	1.20	0.493	0.233	0.122
750	220.0	30.5	7.52	2.54	1.04	0.493	0.257
1,000	375.0	52.0	12.8	4.32	1.78	0.839	0.438
1,500	—	110.0	27.1	9.14	3.76	1.78	0.928
2,000	—	—	46.2	15.6	6.41	3.30	1.58
2,500	—	—	—	23.5	9.69	4.57	2.39
3,000	—	—	—	33.0	13.6	6.41	3.34
4,000	—	—	—	—	23.1	10.9	5.69
5,000	—	—	—	—	34.9	16.5	8.60

*For values of c different from 100, multiply the flow rates listed in Table C2.8 by the conversion factors listed in Table C2.9.

†For approximate interpolation between the *tabulated flows*, calculate the actual flow as a percent of the next lower tabulated flow, convert this percent to the given value in Table C2.10 and take this percent of the friction loss corresponding to the lower tabulated flow.

‡Nominal pipe diameters were used in calculating the tabulated friction losses. The inside diameter of pipe conforming to American National Standards Institute or American Water Works Association Standards will vary with the process of manufacture, material, and pressure classification and can be found in the Standards. Some published tables of friction losses are based upon actual internal diameters. The errors caused by minor differences in internal diameter are usually not significant when considered in relation to the uncertainties in assumed coefficients and rates of flow. If desired, adjustment for differences in diameter can be made by applying a factor $d(\text{nominal})^{1.25}/d(\text{actual})^{1.25}$ to the values given in Table C2.10.

The generally accepted formula for estimating friction loss in fire protection piping practice is the Hazen-Williams formula. The form of the Hazen-Williams formula used is:

$$f = \frac{4.52\, Q^{1.85}}{C^{1.85}\, d^{4.87}} \tag{C2.2}$$

Where f = friction loss, psi per ft
Q = rate of flow, gpm
C = Hazen-Williams pipe coefficient
d = internal pipe diameter, in

TABLE C2.9 Conversion for Different Values of C in Williams and Hazen Friction-Loss Table

Value of C	Conversion factor
140	0.537
130	0.615
120	0.714
110	0.836
100	1.000
90	1.22
80	1.51
70	1.93
60	2.57

In metric units, the formula is:

$$f = \frac{6.05\ Q^{1.85}}{C^{1.85}\ d^{4.87}} \tag{C2.2M}$$

Where f = friction loss, bars per m
Q = rate of flow, L/min

TABLE C2.10 Interpolation for Water Flows between Values Given in Table C2.8

Actual flow as % of next lower tabulated flow	Converted % to be applied to friction loss at next lower tabulated flow
105	110
110	120
115	130
120	140
125	151
130	162
135	174
140	186
145	198
150	211
160	238
180	296
200	361

Example: 8-in. pipe, flow 650 gpm.
Next lower tabulated flow 500 gpm.
Percent of lower flow = 650 ÷ 500 = 130 percent.
Converted percent = 162.
Tabulated lower friction loss at 500 gpm = 3.53.
Approximate actual friction loss = 3.53 × 130 percent = 4.58 psi/1,000-ft.

C = Hazen-Williams pipe coefficient
d = internal pipe diameter, mm

The value for coefficient C varies with pipe type and internal pipe conditions. The lower the capacity-carrying characteristics of the pipe, the lower the value of C. Table C2.6 lists C values for various pipe internal surfaces.

Increasing age generally decreases the capacity-carrying characteristics of unlined steel and cast-iron pipe. The variations of C with age from mildly corrosive water is shown in Table C2.7. Table C2.8 gives the friction loss of nominal pipe in psi per 1000 ft. When using Table C2.8, note the references to Tables C2.9 and C2.10.

Appendix E4 in this handbook contains additional pressure drop tables for different sizes of pipe.

The degradation of C accelerates with moderately or severely corrosive water. In these cases, the coefficient may be reduced to 60 to 75 for 15-year-old pipe. A coefficient of $C = 100$ is commonly used for average or new conditions. In sections of fire protection pipe in which there is normally no flow, such as sprinkler systems, deterioration is less rapid. For underground piping, lined nonmetallic pipe typically exhibits little decrease in capacity over time.

For moderate- and high-pressure water mist systems with pressures above 175 psi (1.2 MPa), the Hazen-Williams equation is not considered sufficient, and hydraulic calculations must be performed using the Darcy-Weisbach method. This method should also be used for water-based systems with additives, since this method can accommodate fluid densities and viscosities other than those of water.

The determination of proper pipe size for gaseous suppression systems is by complex floor calculations that consider the two phase (i.e., liquid and vapor) characteristics of the agent flowing through the pipe network. These calculation methods consider storage pressure, rate of pressure reduction, elevation line pressure, heat transfer of the piping network, density, and other factors. Details on acceptable calculation methods can be found in NFPA 12 for carbon dioxide systems and NFPA 12A for Halon systems.