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Comparison of Fire Sprinkler Piping Materials: Steel, Copper, Chlorinated Polyvinyl Chloride and Polybutylene, in Residential and Light Hazard Installations

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Abstract

A literature-based study was conducted at the Building and Fire Research Laboratory of the National Institute of Standards and Technology, to compare characteristics and usage of steel, copper, chlorinated polyvinyl chloride, and polybutylene fire sprinkler pipe primarily related to residential and light hazard installations. This report addresses key variables such as material properties, usage criteria and limitations, system design, installation requirements, economics, and maintenance. Information is presented which is useful for the selection of a sprinkler pipe material. This study was sponsored by the United States Fire Administration.

Key Words: building technology; copper; CPVC; fire research; PB; pipe; plastic pipe; polybutylene; sprinkler systems; steel; tube

1.0 INTRODUCTION

The National Fire Protection Association (NFPA) reports that the first form of fire sprinkler system installed in the United States was a perforated pipe system installed in 1852 [1]. The first automatic sprinkler was invented in 1864. Over the years, the fire sprinkler has developed and changed as has the piping system serving it. The first fire sprinkler piping was black iron, which was replaced by steel piping in 1892. In the 1960s copper tube[1] entered the fire sprinkler market. In the 1980s chlorinated polyvinyl chloride (CPVC), polybutylene (PB), and lightwall steel sprinkler pipe were listed for use in fire sprinkler systems[2] [2]. Since the introduction of these piping materials, the installation of fire sprinkler systems has increased.

The NFPA has developed installation standards to address the installation of fire sprinkler systems; NFPA 13, "Standard for the Installation of Sprinkler Systems," is the primary sprinkler system standard. NFPA 13D, "Standard for Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes," and NFPA 13R, "Standard for the Installation of Sprinkler Systems in Residential Occupancies up to and Including Four Stories in Height," specifically address residential fire sprinkler systems [3-5].

Table 1 of this report, adapted from NFPA 13, table 2-3.1, lists pipe or tube materials specified for use in fire sprinkler systems. Pipe or tube materials specified for use in NFPA 13D and 13R are shown in tables 2 and 3 of this report, as adapted from tables 3-3.1 and 1-5.1 of the respective standards. Table 4 of this report, adapted from NFPA 13, table 2-3.5, specifies pipes that have been specially listed for use in fire sprinkler systems. The same table is found in NFPA 13D and NFPA 13R as table 3-3.2 and table 1-5.2, respectively. Provisions in NFPA 13, 13D, and 13R allow for the use of materials other than those specifically cited in the tables, provided the materials are listed for use in fire sprinkler systems by an approved laboratory and installed according to their listing limitations and the manufacturer's installation instructions. Section 2-3.5 of NFPA 13 states:

> Other types of pipe or tube investigated for suitability in automatic sprinkler installations and listed for this service, including but not limited to polybutylene, chlorinated polyvinyl chloride (CPVC), and steel differing from that provided in Table 2-3.1, shall be permitted when installed in accordance with their listing limitations, including installation instructions. Pipe or tube shall not be listed for portions of an occupancy classification. Bending of pipe conforming to 2-3.5 shall be permitted as allowed by the listing.

Similar provisions are stated in sections 3-3.2 and 1-5.2 of NFPA 13D and 13R, respectively.

The United States Fire Administration has sponsored the Building and Fire Research Laboratory of the National Institute of Standards and Technology to prepare a literature-based report which compares the

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[1] Steel and CPVC sprinkler material is typically referred to as pipe. Copper and PB sprinkler material is typically referred to as tube. The term "tube" is used throughout the text when referring to copper or PB specifically. However, for the purpose of brevity, the terms "pipe" or "piping" are used when referring to copper and/or PB in conjunction with steel or CPVC.

[2] CPVC and PB fire sprinkler pipe discussed in this report refer to CPVC and PB pipe that is UL (Underwriters Laboratories) listed for use in fire sprinkler systems.

characteristics and usage of steel, copper, CPVC, and PB sprinkler piping for use in fire sprinkler systems primarily related to residential and light hazard installations. While all of these materials are capable of transporting water to the sprinklers, each has advantages and disadvantages; there are many factors to consider when deciding on a product for a specific piping application. This report presents information to aid in decisions regarding selection of a sprinkler pipe material in the aforementioned occupancies.

Table 1. NFPA 13 Pipe or Tube Materials and Standards
(adapted from NFPA 13 Table 2-3.1)

Materials	Standard
Ferrous Piping (Welded and Seamless)	
†Spec. for Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless Steel Pipe for Fire Protection Use	ASTM A795
†Spec. for Welded and Seamless Steel Pipe	ANSI/ASTM A53
Wrought-Steel Pipe	ANSI B36.10M
Spec. for Elec-Resistance Welded Steel Pipe	ASTM A135
Copper Tube (Drawn, Seamless)	
†Spec. for Seamless Copper Tube	ASTM B75
†Spec. for Seamless Copper Water Tube	ASTM B88
Spec. for General Requirements for Wrought Seamless Copper and Copper-Alloy Tube	ASTM B251
Fluxes for Soldering Applications of Copper and Copper Alloy Tube	ASTM B813
Brazing Filler Metal (Classification BCuP-3 or BCuP-4)	AWS A5.8
Solder Metal, 95-5 (Tin-Antimony-Grade 95TA)	ASTM B32

†Denotes pipe or tubing suitable for bending (see 2-3.6) according to ASTM standards.

Table 2. NFPA 13D Pipe or Tube Materials and Standards (adapted from NFPA 13D Table 3-3.1)

Materials	Standard
Specification for Welded and Seamless Steel Pipe	ASTM A53
Wrought-Steel Pipe	ANSI B36.10M
Specifications for Electric-Resistance Welded Steel Pipe	ASTM A135
Copper Tube (Drawn, Seamless) Specification for Seamless Copper Tube	ASTM B75
Specification for Seamless Copper Water Tube	ASTM B88
Specification for General Requirements for Wrought Seamless Copper and Copper-Alloy Tube	ASTM B251
Fluxes for Soldering Applications of Copper and Copper Alloy Tube	ASTM B813
Brazing Filler Metal (Classification BCuP-3 or BCuP-4)	AWS A5.8
Specification for Solder Metal, 95-5 (Tin-Antimony-Grade 95TA)	ASTM B32

Table 3. NFPA 13R Pipe or Tube Materials and Standards (adapted from NFPA 13R Table 1-5.1)

Materials	Standard
Specification for Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless Steel Pipe for Fire Protection Use	ASTM A795
Specification for Welded and Seamless Steel Pipe	ASTM A53
Wrought-Steel Pipe	ANSI B36.10M
Specification for Electric-Resistance Welded Steel Pipe	ASTM A135
Copper Tube (Drawn, Seamless) Specification for Seamless Copper Tube	ASTM B88
Specification for General Requirements for Wrought Seamless Copper and Copper-Alloy Tube	ASTM B251
Fluxes for Soldering Applications of Copper and Copper Alloy Tube	ASTM B813
Brazing Filler Metal (Classification BCuP-3 or BCuP-4)	AWS A5.8
Specification for Solder Metal, 95-5 (Tin-Antimony-Grade 95TA)	ASTM B32

Table 4. NFPA 13 Specially Listed Pipe or Tube Materials and Standards (adapted from NFPA 13 Table 2-3.5)

Materials	Standard
Nonmetallic Piping	
Specification for Special Listed Chlorinated Polyvinyl Chloride (CPVC) Pipe	ASTM F442
Specification for Special Listed Polybutylene (PB) Pipe	ASTM D3309

2.0 MATERIAL PROPERTIES

When examining an installed fire sprinkler system, the type of pipe used in the system can be identified by appearance and branding. Steel, copper, CPVC, and PB sprinkler pipes also have different material properties such as the melting point or heat distortion temperature, the coefficient of linear expansion, and the weight per unit length. The coefficient of linear expansion for each material is presented in table 5. The weight per unit length of each material as a function of size is presented in table 6. DN (diameter nominal) is the nominal pipe diameter in metric units of millimeters. NPS (nominal pipe size) is the nominal pipe diameter in English units of inches.

Table 5.
Coefficients of Linear Expansion for Sprinkler Pipes

Material	Coefficient of Linear Expansion (mm/(mm-°C))*
Steel	11.7×10^{-6}
Copper	17.1×10^{-6}
CPVC	61.2×10^{-6}
PB	128.0×10^{-6}

*Multiply the mm/(mm-°C) values in the table by 0.5556 to obtain in/(in -°F).

Table 6.
Sprinkler Pipe Size vs. Weight Comparison of Steel, Copper, CPVC, and PB

Nominal Size DN (mm)	Nominal Size NPS (in)	Steel Pipe Schedule 40 (kg/m)*	Typical Lightwall Steel (kg/m)*	Copper Type M (kg/m)*	CPVC (SDR 13.5) (kg/m)*	PB (SDR 11) (kg/m)*
20	0.75	N/A	N/A	0.49	0.25	0.13
25	1.0	2.50	1.82	0.68	0.39	0.20
32	1.25	3.38	2.35	1.01	0.62	0.31
40	1.5	4.05	2.80	1.40	0.82	0.43
50	2.0	5.43	3.75	2.17	1.28	0.73
65	2.5	8.62	6.07	3.02	1.87	N/A
80	3.0	11.3	7.46	3.99	2.78	N/A

*Multiply the kg/m values in the table by 0.6720 to obtain lb/ft.

2.1 Steel

Steel sprinkler pipe is rigid and usually black in color. Lightwall steel pipe, however, typically has a galvanized exterior, and therefore a silvery appearance. Steel sprinkler pipe conforms to the American Society for Testing and Materials (ASTM) A53, "Specification for Welded and Seamless Steel Pipe"; A135, "Specification for Electric-Resistance-Welded Steel Pipe"; or A795, "Specification for Black and

Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless Steel Pipe For Fire Protection Use" [6-8]. There are several different types of sprinkler pipe conforming to each specification. For each sprinkler pipe variation, individual properties differ, from weight, to wall thickness, to joining methods, to outer and inner diameter values. Typical lightwall steel pipe is also manufactured to meet the requirements of ASTM A135, however, it does not conform to the dimensional requirements of established pipe schedules. This report focuses on the steel pipe used in NFPA 13 light hazard occupancies, NFPA 13D, and NFPA 13R occupancies. Steel sprinkler pipe is sized according to the NPS system. Steel sprinkler pipe is not specified by NFPA for use in fire sprinkler systems in sizes smaller than DN25 (1.0 in.).

According to a manufacturer, the melting point of the steel used in fire sprinkler systems ranges between 1427 °C and 1538 °C (2600 °F and 2800 °F). This is in agreement with the values found in *Marks' Standard Handbook for Mechanical Engineers* [9], which lists the melting point temperatures for various types of steel meeting specific American National Standards Institute (ANSI) standards. Steel sprinkler pipe is pressure rated at 1.21 MPa (175 psi), as is all fire sprinkler piping. Steel pipe has the lowest coefficient of linear expansion of the sprinkler pipe materials discussed in this report. For example, a 30.5 m (100 ft) section will expand only 16 mm (0.63 in) when heated from 4.4 °C to 49°C (40 °F to 120 °F). Dropping, stepping on, or banging steel pipes during installation will not easily cause them damage because of the rigidity and mechanical strength associated with steel when compared to CPVC or PB sprinkler pipe under similar conditions. Steel sprinkler pipe is one of the more rigid sprinkler pipe materials available, however, this rigidity may be less desirable when there are many obstacles to route the pipe around during installation. Ultraviolet (UV) exposure for extended time periods will not adversely affect performance capabilities or mechanical properties of steel. Steel pipe may be painted with no adverse effects.

2.2 Copper

Copper is a brownish, malleable metal. The NFPA first approved copper for use in fire sprinkler systems in 1961. It is sized according to the copper tube size (CTS) system and conforms to ASTM B88, "Standard Specification for Seamless Copper Water Tube" [10]. In the CTS system, a tube's outer diameter is 3.18 mm (0.125 in) greater than its nominal size. Copper sprinkler tube is currently available in three types, K, L, and M. Type M has the thinnest wall. Type L has a thicker wall than type M, followed by type K, which has the thickest wall and thus the smallest internal diameter. Type M is the least expensive, and is the most frequently used in fire sprinkler systems. Copper tubing types K, L, and M are available in drawn (hard) temper, only types K and L are also available in annealed (soft) temper.

Copper sprinkler tube has slightly more flexibility than steel sprinkler pipe, most notable when used in smaller diameters. Types K and L annealed copper tube can be used where bending is required. Each type of tubing has its own set of physical properties, and is available in different tube sizes. Copper tube will melt at 1082 °C (1980 °F), and has a coefficient of linear expansion about 1.5 times that of steel [11]. A 30.5 m (100 ft) section of copper tube will expand 23 mm (0.9 in) when heated from 4 °C to 49 °C (40 °F to 120 °F). UV exposure for extended time periods will not adversely affect its performance capabilities or mechanical properties. A DN25 (1.0 in) type M copper tube weighs 0.68 kg/m (0.46 lb/ft), less than one-third the weight of a schedule 40 steel pipe, and slightly more than one-third the weight of lightwall steel pipe of comparable size. Normal care should be exercised when installing copper sprinkler tube; it is not as susceptible to damage from dropping or stepping on it as CPVC and PB.

2.3 CPVC

CPVC pipe listed for use in fire sprinkler systems is bright orange, lightweight, and is classified as a rigid thermoplastic material[3]. CPVC has been used in hot and cold water applications since 1959, and as industrial pipe since 1962. It was first used as residential sprinkler pipe in 1984, and was listed by Underwriters Laboratories (UL) in 1985 for this application. CPVC sprinkler pipe conforms to ASTM F442, "Standard Specification for Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe (SDR-PR)" [12], has a standard dimension ratio (SDR) of 13.5, and is sized according to the NPS system. The SDR is the ratio of average outside pipe diameter to wall thickness.

According to the manufacturer, CPVC sprinkler pipe has a heat distortion temperature of 103 °C (217 °F), measured in accordance with ASTM D648 [13]. The heat distortion temperature is the temperature at which the pipe begins to soften and lose strength. CPVC has a coefficient of linear expansion over five times that of steel, and about three times that of copper. CPVC pipe will noticeably expand or contract when exposed to substantial temperature differences. For example, a 30.5 m (100 ft) section of CPVC pipe will expand 84 mm (3.3 in) along the length of the pipe when heated from 4 °C to 49 °C (40 °F to 120 °F). There is negligible expansion or contraction circumferentially. The thermal expansion properties of CPVC sprinkler pipe warrant special consideration during installation. Section 7.4 of this report explains the methods used to compensate for dimensional changes due to thermal expansion. DN25 (1.0 in) pipe weighs roughly 0.39 kg/m (0.26 lb/ft), slightly more than one-fifth the weight of lightwall steel pipe and just over one-half the weight of type M copper tube of comparable size.

Reasonable care must be exercised when handling CPVC pipe and fittings. If they are dropped, stepped on, or have objects dropped on them, they should be checked for scratches, splits, or gouges. The damaged sections should be cut out and discarded [14]. If prolonged exposure to the sun's UV rays occurs, the pipe tends to lose drop impact resistance, and becomes less flexible; however, it does not lose any of its long-term hydrostatic strength capability [15]. To protect them from UV rays, CPVC sprinkler pipes are shipped to the installers in bundles, wrapped with an opaque covering or in white cardboard boxes. The amount of pipe in each bundle depends on the pipe size [16]. While it is acceptable to coat CPVC with latex paint, because of potential adverse chemical reactions with the pipe, the manufacturer should be consulted before applying any sealants, fire stop materials, or other types of paint to the pipe.

2.4 PB

PB tube listed for use in fire sprinkler systems is grey, lightweight, and very flexible. The primary use for PB tubing has been in hot water piping applications since the early 1970s. The tubing has since expanded into other markets, including industrial water and chemical transport. PB was first listed by UL for use in residential fire sprinkler systems in 1985. PB sprinkler tubing conforms to ASTM D3309, "Standard Specification for Polybutylene Plastic Hot- and Cold-Water Distribution Systems" [17], has an SDR of 11, and is sized according to the CTS system. PB tube is not specified by NFPA for use in fire sprinkler systems in sizes larger than DN50 (2.0 in).

According to the manufacturer, PB melts between 122 °C and 126 °C (252 °F and 259 °F), determined

[3] ASTM D883 defines a rigid thermoplastic as a plastic that has a modulus of elasticity, either in flexure or in tension, greater than 700 MPa (100,000 psi) at 23 °C and 50 percent relative humidity.

in accordance with ASTM D-3418, "Standard Test Method for Transition Temperatures of Polymers By Thermal Analysis" [18]. PB sprinkler tube has the highest coefficient of linear expansion of all the piping materials, twice that of CPVC. The tube noticeably expands and contracts both linearly and circumferentially. A 30.5 m (100 ft) section of PB tube will expand along the length of the tube about 173 mm (6.8 in) when heated from 4 °C to 49 °C (40 °F to 120 °F). The thermal expansion properties of PB sprinkler tube warrant special consideration during installation. Section 7.4 of this report explains installation methods used to compensate for thermal expansion. The DN25 (1.0 in) tube weighs approximately 0.20 kg/m (0.14 lb/ft), about one-ninth the weight of typical threaded lightwall steel pipe, less than one-third the weight of type M copper tube and about one-half the weight of CPVC pipe of comparable size.

Normal care should be exercised in storage and installation to prevent physical damage to the tube. Any damaged sections containing kinks, deep scratches, penetrations, or abrasions must be cut out and discarded. PB tube is not damaged by exposure to sunlight during normal installation periods of up to 30 days, but should not be used for applications involving extended exposure to sunlight. PB tube should be stored inside or under cover [19]. PB tubes are shipped to the installer in straight lengths, enclosed in black plastic bags to inhibit UV exposure. Depending on nominal size, there are between five and 25 tubes to a bag. The manufacturer should be consulted before applying any sealants, fire stop materials or other types of paint to PB tube [19].

3.0 MATERIAL DEGRADATION

How a fire sprinkler pipe degrades, both under long-term ambient conditions and when exposed to a fire, is an important consideration. Fire sprinkler system piping must remain structurally reliable for several decades and be able to withstand fire conditions to deliver water to the sprinkler heads.

3.1 Corrosion, Scale Build-Up and Sedimentation

Corrosion and scale build-up are factors which affect the life and performance of metal fire sprinkler pipe, while sedimentation is a factor affecting the life and performance of all fire sprinkler piping. Severe corrosion can cause a system to fail by thinning the pipe walls. Scale build-up and sedimentation reduce water flow through the system. Degradation of metal sprinkler pipe due to corrosion and scale-build up is a function of many factors, including the chemical content of the available water supply (sometimes referred to as the corrosivity or aggressiveness of the water), the ambient environmental conditions, how often fresh oxygen is introduced to the system through a system flush, and the pipe material. Sedimentation is a factor of the water supply, the fire sprinkler system's filtering system, and how often fresh oxygen is introduced to the system through a system flush. These are factors to be considered when designing a fire sprinkler system and selecting the pipe material.

Pitting is a form of corrosion which can result in holes in the pipe walls. The typical size of these holes may range from nanometers to millimeters in diameter and depth. According to Fontana and Greene [20], "...from a practical standpoint, most pitting failures are caused by chloride and chlorine-containing ions." These ions are usually found in the water supply present in the fire sprinkler system. Fontana and Greene also state that "...perhaps the best explanation [of pitting] is the acid-forming tendency of chloride salts and the high strength of its free acid (HCl)" [20]. In cases of severe pitting, the wall integrity is compromised, and leaks or ruptures may occur. One method used to reduce the risk of failure from pitting is to increase pipe wall thickness. Since pitting is a penetrating action, increasing wall thickness serves to delay a potential breach.

Scale build-up is the term used to describe the build-up of deposits on the internal pipe wall. Typically, calcium and magnesium precipitates from the water and binds with the pipe wall. Over time, this collection will result in a constriction of the pipe internal diameter. This internal diameter, in addition to other factors, determines how much and how quickly water will flow to the sprinkler heads when activated. A large scale build-up may significantly impede water flow to the heads. Furthermore, this build-up carries with it the potential to flake off. During a sprinkler head activation, water will flow through the pipes, imposing a force on the pipe walls. This force may be sufficient to break off some of the scale build-up, and carry it downstream toward the sprinkler heads, potentially blocking discharge from the sprinkler orifice.

Sedimentation describes the settling of debris in the water supply on the pipe walls when the water stagnates. The accumulation of debris serves to slow down the water flow during an activation event. Sedimentation is independent of the sprinkler pipe material. An adequate filtering system will reduce sedimentation build-up in a piping system.

3.1.1 Steel

Battelle Laboratories has performed corrosion testing in fire sprinkler systems for the steel industry. The study found that the three factors leading to the heaviest attack on the pipe were oxygen availability, presence of sediment or debris, and galvanic couples [21]. Sprinkler systems contain static water for the majority of their lives. During the yearly system flushes, fresh water, which contains oxygen, is introduced to the system. This oxygen is quickly used up to corrode the pipe through an oxidation process; once consumed, no significant corrosion occurs until the next system flush when fresh oxygen is once again introduced into the system. The report further states that, "...as this first corrosion is formed, a protective layer [of scale build-up] is generated which will retard additional corrosion [pitting] from forming each time fresh water is reintroduced into the system" [21]. A method used to reduce the detrimental effects of corrosion on steel walls is to coat the walls with zinc. Zinc is more reactive than steel, and as such acts as a sacrificial material, reacting first with the corrosion forming components to perform the protective layer of scale build-up, thus protecting the steel.

With the introduction of thinner walled, lighter weight steel pipes, concerns regarding the service life of these lightwall steel pipes arose. A Battelle Laboratory study addressed these concerns by predicting the performance of lightwall steel pipe based on observed corrosion performance of schedule 40 steel pipe in fire sprinkler systems. Fifty-six specimens were taken from 41 installations located in various parts of the country. To predict the probable performance of lightwall steel pipe, both linear and non-linear rates of pitting were calculated from the maximum pit depths and period of service for each schedule 40 specimen. Assuming that the average rate of pitting occurred at the minimum wall thickness, service lives for lightwall steel pipe and schedule 40 steel pipe were estimated. The report concludes that, "On the basis of the examination of the schedule 40 [steel] pipe specimens and an extrapolation of the results to ALWP (lightwall steel pipe) it can be estimated the ALWP would provide satisfactory performance in most sprinkler systems up to and exceeding 100 years" [21].

This however is just one study on a specific lightwall steel pipe. Lightwall steel pipe varies in wall thicknesses and also in installation methods. Pipe that is threaded has a minimum wall thickness at the first exposed thread. UL assigns each type of steel pipe and associated installation method a corrosion resistance ratio (CRR). This ratio for each pipe size is defined as:

$$CRR = \frac{X}{X_{40}}$$

X_{40} = thickness of schedule 40 steel pipe under the first exposed thread[4]
X = thickness of the listed pipe measured either under the first exposed thread for threaded pipe or at the thinnest wall section for unthreaded pipe

The CRR will be greater than 1.00 when the wall thickness of the listed pipe is greater than the wall thickness of schedule 40 steel pipe under the first exposed thread and less than 1.00 when the listed pipe wall is thinner than the wall thickness of schedule 40 steel pipe under the first exposed thread. It is important to understand that the corrosion resistance ratios are a function of relative wall thickness when compared to schedule 40 steel pipe. While a corrosion resistance ratio of less than 1.00 implies a service life less than that of schedule 40 steel pipe exposed to similar conditions, it does not imply that the lightwall steel pipe cannot provide the needed service life. The corrosion performance of steel pipe can vary depending on the composition of the steel from which it is formed, the composition of the water to which it is exposed, and the related service conditions [22].

Corrosion resistance ratios for lightwall steel pipe vary with the manufacturer, type of pipe, and whether or not the pipe is threaded. Not all lightwall steel pipes are listed to be joined by threading. Typical threaded lightwall steel pipe has corrosion resistance ratios of 0.35 for DN25 (1.0 in) pipe down to 0.21 for DN50 (2.0 in) pipe. Some manufacturers have other sizes listed and varying corrosion resistance ratios. The UL specifications should be consulted for the CRR of a specific product and size pipe. For unthreaded lightwall steel pipe, the listing for most products includes corrosion resistance ratios that are greater than 1.00 for the smaller diameter pipes (less than approximately DN65 (2.5 in) and less than 1.00 for the larger diameter pipes. Again the UL specifications should be consulted for the CRR of a specific product [22].

3.1.2 Copper

A somewhat noble metal, and therefore less likely to react with corrosive chemicals, copper tube tends to corrode very slowly in most water supplies. Pure copper resists attack quite well under most corrosive conditions, however, different copper alloys may be less resistive under certain conditions. In time, copper tube is given to pitting and scale build-up, but the process is not as active as it is with steel pipe and is therefore less of a concern. As with steel, if scale build-up occurs in a copper system, the build-up may serve as a protective layer resisting further corrosion from pitting.

Parameters that may accelerate corrosion in copper tubing are a low pH value (less than 7.8) of the water supply and/or a high free carbon dioxide concentration. Sulfate, sulfate to chloride ratio, and dissolved oxygen have been hypothesized as causative factors in copper pitting. An extensive discussion of corrosion of copper and copper alloys is given by Cohen in *Process Industries Corrosion-Theory and Practice* [23].

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[4] UL defines the "first exposed thread" as the minimum pipe thickness exposed to both interior and exterior corrosion and occurs at the threaded joint assembly at a line defined by the thread width, just before the pipe engages the fitting.

3.1.3 CPVC and PB

All sprinkler piping materials are subject to sedimentation of debris in the water supply. However, because of their inert nature, CPVC and PB pipes have been found to be resistant to scale build-up and pitting.

CPVC and PB sprinkler pipe have been put through corrosion tests for a variety of potentially damaging chemicals [24, 25]. Many of the chemicals tested are known to cause corrosion in metal pipe, and are found in most water supplies. Both raw material suppliers distribute extensive lists of the chemicals tested for corrosive effects. Since the temperature of the water in the pipes affects the rate at which these chemicals attack the pipe, CPVC has been tested at temperatures of 23 °C (73 °F) and 82 °C (180 °F); PB has been tested at 22 °C (72 °F) and 60 °C (140 °F) [24, 25].

The CPVC data show that it is resistant to attack by mineral acids, bases, salts, and paraffinic hydrocarbons. The PB data shows that it is resistant to attack by most aqueous salts, bases, and acids. Test data is from 30-90 day accelerated testing. Both reports caution, however, that various use conditions such as operating temperatures, chemical reagents or mixtures, chemical concentrations and other factors can also affect the chemical resistance of plastic piping systems [24,25].

Extended exposure to certain levels of chlorine have been shown to degenerate PB tube in hot water plumbing systems. Tests were conducted with chlorine levels up to and including 2.0 parts per million (ppm) in systems with continuously flowing water. Hot and cold water were cycled through the pipes. For pipe exposed to water at 23 °C (73 °F) for 85 percent of the time and 60 °C (140 °F) for 15 percent of the time, the extrapolated test life for PB tube is 85 years. PB tube has not been tested for exposure to chlorine levels greater than 2.0 ppm, nor has it been tested under typical fire sprinkler system conditions, i.e predominantly stagnant water at constant ambient temperature. The manufacturer recommends that PB sprinkler tube not be used in areas where continued or prolonged exposure to chlorine levels of 2.0 ppm exist [26]. Domestic water supplies across the country generally contain between 0.2 and 4.0 ppm of chlorine, depending on the quality of the water supply and the dispersion of the chlorine throughout the system. It is important to consult local authorities with regard to chlorine levels before installing a PB system.

3.2 Galvanic Corrosion

A potential difference usually exists between two dissimilar metals placed in contact, resulting in galvanic corrosion. According to Fontana and Greene [20], this potential difference produces electron flow between them [the metals]. In this situation, corrosion of the less corrosion-resistant metal usually increases, and corrosion of the more corrosion-resistant metal decreases, as compared with the behavior of these metals when they are not in contact. One manufacturer accomplishes the transition from steel to copper, which tends to be affected by galvanic corrosion, by using special connectors called dielectric unions. These connectors permit the transition between two dissimilar metals, without the associated galvanic corrosion problems.

The potential for galvanic corrosion is also a consideration during installation of a CPVC or PB system. No fire sprinkler system is 100 percent plastic; at some point the plastic pipe system is joined to a metal pipe, for example, at the vertical riser. Limited test data are available to determine how corrosion of the metal parts of a fire sprinkler system affect the plastic components in the system. CPVC and PB piping systems both use fittings that consist of brass threaded inserts. Since brass is cathodic to iron, which may be present in the metal components of the fire sprinkler system, localized galvanic corrosion may occur when brass and iron are in contact. Here, penetration of the iron film is induced, potentially causing leaks to occur in the piping system.

When connecting CPVC pipe to metal pipe, teflon tape is wrapped around the metal pipe threads before being joined to the brass threaded insert of the CPVC system; PB systems also require teflon tape when using male and female threaded connectors to join a PB and metal pipe system. According to one manufacturer [27], "...some local codes may not allow plastic to metal contact. In this case, plastic sleeves or vinyl electrical tape can be used to isolate the materials." Furthermore, "...male and female threaded adapters or flanges are listed for connecting the CPVC system to other materials.... A thread sealant shall be used in making threaded connection. Teflon thread tape is the recommended sealant and must be used with all threaded connections. Some sealants contain solvents that may be damaging to CPVC" [28].

3.3 Exposure to Fire

Neither steel nor copper will burn, support combustion, or decompose into toxic gases during a fire involving ordinary combustibles.

CPVC and PB fire sprinkler pipe behave differently when exposed to an open flame. CPVC sprinkler pipe is a rigid thermoplastic material; it will char, not melt, upon the application of heat. Among the products of combustion for CPVC are water (H_2O), carbon monoxide (CO), carbon dioxide (CO_2) and hydrochloric acid (HCl). The PB sprinkler tube is a thermoplastic and will melt and drip when exposed to open flame. The major products of combustion of PB are H_2O, CO and CO_2.

As discussed in sections 2.3 and 2.4 of this report, CPVC sprinkler pipe has a heat distortion temperature of 103 °C (217 °F) and PB sprinkler tube melts between 122 °C and 126 °C (252 °F and 259 °F). UL approval reports state that results of the crib fire exposure and sprinkler response fire exposure tests demonstrated the ability of these pipes to supply the required water to the sprinkler under fire conditions when the pipe is protected as required in the manufacturer's installation instructions [15]. Specific protection requirements are discussed in sections 5.2 and 5.3 of this report. It is important that where protection of the CPVC or PB pipe is required, the integrity of the protection be maintained throughout the service life of the fire sprinkler system.

4.0 OCCUPANCY CLASSIFICATIONS

Steel and copper pipe are specified for use in NFPA 13, 13D, and 13R installations. Both CPVC and PB pipe are specified for use in NFPA 13 light hazard occupancies, NFPA 13D, and NFPA 13R installations. Light hazard occupancies are defined by NFPA 13 as "Occupancies or portions of other occupancies where the quantity and/or combustibility of contents is low and fires with relatively low rates of heat release are expected." Examples of light hazard occupancies include churches, clubs, hospitals, schools, museums, theaters, office buildings, as well as residential occupancies such as nursing homes and hotels. Examples of NFPA 13R occupancies are apartment buildings, lodging and rooming houses, motels, and dormitories up to four stories in height. Steel, copper, and CPVC pipe and fittings have been found to comply with the combustibility requirements for sprinkler pipe as described in NFPA 90A, "Standard for Installation of Air Conditioning and Ventilating Systems" [29]. Because NFPA standards are voluntarily adopted, in whole or in part, by local jurisdictions, local codes should be consulted before any type of sprinkler pipe material is installed.

To obtain UL approval for use in fire sprinkler system applications, steel pipe must pass Subject 852, "Outline of Investigation for Steel Sprinkler Pipe For Fire Protection Service" [30]. For the same UL approval, plastic pipe must pass Subject 1821, "Outline of Investigation For Thermoplastic Sprinkler Pipe and Fittings For Fire Protection Service" [31]. Plastic pipe must pass UL 1887, "Fire Test of Plastic Sprinkler Pipe for Flame and Smoke Characteristics," for use in plenum spaces as defined in NFPA 90A [32].

5.0 SPECIFIC INSTALLATION REQUIREMENTS

5.1 Steel and Copper

NFPA 13 [3] does not permit welding of fire sprinkler pipe in place inside existing occupancies; the welding must be performed at the contractor or fabricator's premise or at an approved welding area at the building site. Welding in place is permitted, however, in new buildings under construction when the area is free of combustible construction or combustible components.

Copper fire sprinkler tubing must be joined by the brazing method discussed in section 6.2 of this report when installed in dry systems. Solder joints are permitted for exposed wet pipe systems in light hazard occupancies where the operation temperature of the installed sprinklers is classified by NFPA as ordinary or intermediate [1]. Solder joints are also permitted for wet pipe systems where the piping is concealed, irrespective of the operation temperature of the installed sprinklers. Other restrictions apply as stated in the NFPA installation standards.

5.2 CPVC

Accompanying the UL approval listing of CPVC pipe [33] is a set of restrictions providing for protection of the pipe from exposure to open flame. For concealed installation in light hazard occupancies as defined in NFPA 13, the minimum protection for both the CPVC piping and the CPVC fittings must be one of the following:

1) one layer of 9.5 mm (0.38 in) gypsum wallboard, *or*

2) a suspended membrane ceiling with lay-in panels or tiles having a distributed weight of not less than 16.8 N/m^2 (0.35 lbf/ft^2) when installed with metallic support grids, *or*

3) 12.7 mm (0.5 in) plywood soffits.

For NFPA 13D and 13R occupancies, the minimum protection may consist of one layer of 12.7 mm (0.5 in) plywood.

According to the April, 1992 UL guide card in [28], CPVC pipe and fittings may be installed without ceiling protection (exposed) when subject to certain limitations. These limitations require that:

1) exposed piping be installed below a smooth, flat, horizontal ceiling, *and*

2) listed quick response pendent sprinklers have deflectors installed within 203 m (8.0 in) from the ceiling or listed residential pendent sprinklers be located in

accordance with their listing and at a maximum distance between sprinklers not to exceed 4.57 m (15 ft), *or*

3) listed quick-response horizontal sidewall sprinklers have deflectors installed within 152 mm (6.0 in) from the ceiling and within 102 mm (4.0 in) from the sidewall or listed residential horizontal sidewall sprinklers be located in accordance with their listing and a maximum distance between sprinklers not to exceed 4.27 m (14.0 ft).

CPVC sprinkler pipe is not listed for use in dry pipe fire sprinkler systems. CPVC pipe shall be used in fire sprinkler systems where the operation temperature of the installed sprinklers is 77 °C (170 °F) or lower. CPVC pipe and fittings are not listed for use in combustible concealed spaces where sprinkler protection is required by NFPA 13. NFPA 13D and 13R do not require automatic sprinkler protection in combustible concealed spaces; CPVC pipe and fittings may be installed in these locations. [27]

CPVC sprinkler pipe, when installed in a plenum space, must be installed at a horizontal distance of at least 0.61 m (2 ft) from openings in the ceiling such as ventilation grills [14].

CPVC pipe and fittings are intended for use where the ambient temperature is between 0 °C and 66 °C (32 °F and 150 °F). CPVC pipe and fittings are not to be installed in outdoor applications. Freeze protection must be included when installing any fire sprinkler system in an area subject to freezing temperatures. Freeze protection may be achieved by properly insulating the pipe or by using certain antifreeze solutions in the water. There is potential for adverse chemical reactions between CPVC pipe and certain antifreeze solutions. The manufacturer states that CPVC can be used safely with glycerine solutions, while propylene glycol solutions are not recommended [14].

CPVC is sensitive to some petroleum based products and fire-rated sealants. Petroleum-based products may dissolve CPVC, or promote crack propagation in the pipe, depending on the specific product. Petroleum is commonly found on steel systems as a lubricant; care must be taken to avoid contact of this lubricant when joining a CPVC sprinkler pipe or fitting to a metal pipe or fitting. Fire rated sealants, used when penetrating a fire wall, should be selected in accordance with the CPVC pipe listing, and the manufacturer's guidelines.

5.3 PB

Accompanying the UL approval listing of PB tube is a set of restrictions providing for protection of the tube from exposure to open flame [34]. The minimum protection for PB tube and fittings when installed in light hazard occupancies as defined by NFPA 13 must be one of the following:

1) one layer of 12.7 mm (0.5 in) gypsum wallboard, *or*

2) acoustical ceiling panels with steel framing members classified as fire resistive, *or*

3) 12.7 mm (0.5 in) plywood soffits.

For NFPA 13D and 13R occupancies, the minimum protection may consist of one layer of 12.7 mm (0.5 in) plywood. PB tubing is not listed for any exposed installations. PB tube and fittings are not listed for use in combustible concealed spaces where sprinkler protection is required by NFPA 13. NFPA 13D and 13R do not require automatic sprinkler protection in combustible concealed spaces; PB tube and fittings may be installed in these locations. [19]

PB sprinkler tube is not listed for use in dry pipe systems. PB tube is for use in areas where the ambient temperature does not exceed 49.0 °C (120 °F). The operation temperature of the installed sprinklers cannot be higher than the NFPA temperature classification of intermediate. For freeze protection in PB tubing, the manufacturer of the PB resin recommends ethylene glycol, propylene glycol, methanol, or glycerin. However, NFPA 13 states that only glycerin or propylene glycol solutions are acceptable for use in systems supplied by potable water connections.

PB is sensitive to some petroleum based products and fire-rated sealants. Petroleum based products may soften the material, or propagate the destruction of molecular bonds, causing a brittle breakdown of the material, depending on the specific product. Petroleum is commonly found on steel systems as a lubricant; care must be taken to avoid contact of this lubricant when joining a PB sprinkler tube or fitting to a metal pipe or fitting. Fire rated sealants, used when penetrating a fire wall, should be selected in accordance with the PB tube listing, and the manufacturer's guidelines.

6.0 METHODS FOR JOINING PIPE

CPVC and PB sprinkler pipe present quick and easy connection methods compared to more traditional connection methods such as brazing, soldering, and welding. Other pipe joining methods, such as threaded or grooved fittings, provide for easy connections at the site but require previous off-site fabrication. However, similar to all pipe joining methods, if not performed correctly, faulty joints may result. Installers of CPVC and PB sprinkler pipe must pass a one-day training course and obtain a certificate. Joining steel and copper pipe and fittings generally requires more extensive training, and the joining methods may tend to add time to the installation period.

6.1 Steel

Steel pipe is usually joined by threaded, grooved, flanged or plain-end fittings. Steel pipe DN50 (2.0 in) and smaller is usually joined using threaded or plain-end fittings. Steel pipe DN65 (2.50 in) and larger is joined using threaded, flanged or grooved fittings. Grooved fittings are usually the first option because they require the least installation time. Prefabrication is generally done off the job site, at a shop containing the heavy equipment necessary to perform the procedure. These fabrication shops perform cutting, threading, welding and grooving operations in large-scale assembly-line fashion. Installation of steel fire sprinkler pipe generally requires significant training and instruction.

6.2 Copper

Two methods commonly used for joining copper tube and fittings are soldering and brazing. For both methods, instruction and qualification of workers may be provided at the job site. Soldering and brazing are performed using standard torches and a variety of gases. As with steel sprinkler pipe, installation of copper tube systems generally requires significant training and instruction.

Copper tube systems are joined with solder, either in the field or in the shop, according to ASTM B828, "Standard Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings" [35]. This standard explains soldering as "...the process that produces a coalescence of materials by heating them to the soldering temperature and by using a filler metal (solder) having a liquidus not exceeding 450 °C (842 °F) and below the solidus of the base metals." Most soldering is performed at temperatures between 177 °C and 349 °C (350 °F to 660 °F).

The first step in the soldering process is to measure and cut the tube to the required length. Once cut, the end must be reamed to remove the small burrs created by the cutting process. Oxides and surface debris are then removed from the tube end and fitting cup with an abrasive cloth. A thin, even coat of flux is then applied to the tube and fitting as soon as possible after cleaning. Care should be taken not to apply excess flux on the joint as flux residue inside the tube may cause corrosion. ASTM B813, "Standard Specification for Liquid and Paste Fluxes for Soldering Applications of Copper and Copper Alloy Tube," sets the requirements for liquid and paste fluxes that are flushable in water to help alleviate this concern [36]. Flux is an important component of the copper soldering process for many reasons: it acts to dissolve and remove traces of oxide from the cleaned surfaces that are to be joined, it protects those surfaces from reoxidation during the heating process, flux also promotes wetting and uniform spreading of the molten solder.

After these steps have been taken, the tube is inserted into the prefluxed fitting. The space between the tube and fitting, the capillary space, is approximately 0.1 mm (0.004 in) wide. Solder metal is used to fill this gap by capillary action. If the gap is too large or too small, a potentially faulty joint may result. Heating is performed using a torch that is applied perpendicular to the tube; the extent of necessary heating is dependent on the size of the joint. It is important to exercise caution during this stage of the installation, as heating the tube sometimes requires working with the torch in close proximity to combustible materials. Typical air/fuel torches use acetylene, liquefied petroleum gas, or mixed gases. The flame is then moved over the fitting cup, and then alternated across the tube and fitting. With the torch held at the base of the cup, solder is touched at the face of the joint, where the solder begins to melt, and is drawn by capillary action into the space between the tube end and fitting cup. According to ASTM 828, the joint should be allowed to cool naturally, as shock-cooling with water may present the joint with unnecessary stress. When open flames must be avoided, electric resistance soldering hand tools are available for joining.

Brazing is another method for joining copper tubes and fittings. Brazing is required for dry pipe systems and for certain exposed wet pipe systems. The filler metals used in brazing melt at temperatures ranging between 593 °C and 816 °C (1100 °F and 1500 °F) and are specified in the American National Standards Institute (ANSI) A5.8, "Specification for Filler Metals for Brazing" [37]. Brazing fluxes are water-based. Brazing fluxes serve many purposes, including protecting the metal surface from reoxidizing during heating, and promoting the wetting of the surfaces to be joined. The first step in the brazing process is to measure and cut the tube and fittings to the required length. The surfaces are cleaned and prepared in the same manner as the soldering process, and the brazing flux is applied to them. The tube is then inserted into the fitting. Next, the tube is heated, preferably using an oxy-fuel flame, with an air-fuel flame used on smaller size tubes. Heat is applied with a torch about 25 mm (1.0 in) away from the fitting, with continuous motion around the tube. When the flux becomes transparent, the flame is moved over the fitting, and then swept along the axis of the joint, using continuous motion. The brazing filler metal is then applied at the point where the tube enters the fitting socket. The brazing filler material will flow into the space between the tube and fitting. Excess flux is removed with warm water when the joint has cooled.

Also used to form joints in the copper tube fire sprinkler system is the T-drill. The T-drill allows both main and supply lines to be installed with little or no pre-fabrication by simply drilling an outlet. This drill allows a smaller diameter connection to be drilled into a copper tube at any point. It simply drills out holes in a sprinkler line, through which another tube can be connected. These holes are then connected to other tubes, eliminating the need for fittings. Due to the shallow fitting cup, joints created using this process cannot be soldered. Brazing is required here because the brazing filler metal has higher filler strength.

Roll-grooved tubing, which provides for mechanical joining methods similar to those used in steel pipe systems, is available for copper tube systems. Tubes sized between DN50 and DN150 (2.0 in and 6.0 in), together with 45- and 90-degree elbows, straight tees, reducers/expanders, flange adapters and butterfly valves are available for connection using this method.

6.3 CPVC

The CPVC manufacturers offer a one-day hands-on installation training course at no cost. A company representative will travel to the installer location or installation site, and instruct the workers in CPVC installation procedures. Included in this instruction may be a 25-minute training video. Upon completion of this course, the workers are issued certification cards. These cards list the date of issue accompanied by a recommended renewal date.

CPVC pipes are joined to fittings through the use of a solvent cement and primer method, which creates a chemically fused joint. The pipe is cut with a tubing cutter, or with a power or hand saw. Once cut, burrs and filings are removed using a motorized or hand-held chamfering tool which bevels the edges, producing a smooth surface. A small chamfer is made at the pipe end to allow easier entry of the pipe into the fitting socket. The end is then cleaned of loose dirt and moisture using a clean, dry rag. A primer is applied to both the outside of the pipe end and to the inside of the fitting socket, so that the surfaces are completely wet. Immediately after applying the primer, the solvent cement is heavily applied to the outside pipe end, and minimally applied to the inside of the fitting socket. The pipe is then inserted into the fitting socket, rotated a quarter turn, and held for 15 seconds.

The joint must be not be stressed for one to five minutes. It should be emphasized that the proper amount of both chemicals should be applied. Either an excess or a deficiency in chemical application may result in a faulty joint. If too little cement or primer is applied, the joint may not be solid; this may show up as a leak during the pressure test. If excessive cement or primer is applied, however, the pressure test may not reveal this, and the water flow may be impeded during an activation event. The joining process may be performed by a single person and at the site in a few minutes. Curing times, which range between 3 hours and 48 hours, are dependent on pipe size, temperature, relative humidity, and fit tightness. Table 7 shows the average minimum cure time prior to the pressure test [27]. It should be noted that the primer and solvent used in the fitting joining process contain "...highly volatile solvents which evaporate rapidly" [38]. A manufacturer recommends that a fan be placed in the work area to properly circulate the air and dissipate the fumes.

Table 7.
CPVC Curing Times vs. Nominal Pipe Size

Ambient Temperature* During Cure Period	Cure Time	
	DN20 to DN40	DN50 to DN80
Above 15.6 °C	3 hours	5 hours
4.4 °C to 15.6 °C	24 hours	24 hours
-17.8 °C to 4.4 °C	48 hours	48 hours

*To convert from°C to°F, multiply the values in the table by 9/5 and add 32. E.g., 15°C = 59 °F.
Refer to table 5 for the corresponding nominal pipe sizes in inches.

According to one publication, manufacturer notices point out that "...sprinklers should be installed on drops only after the system piping has been assembled" [39]. If manufacturer instructions are not correctly followed, potential exists for the "...solvent cement to drip into pendent sprinkler drops during installation of CPVC pipe and fittings...," which may render the sprinkler inoperative [39].

6.4 PB

PB tubes are joined to fittings using either a heat fusion or a crimping process. The fusion process involves the connection between PB tube and PB fittings, whereas the crimp method joins a copper or brass fitting to the PB tube. The PB manufacturers offer a one-day hands-on installation training course at no cost.

The fusion method requires a tool which must be electrically heated to temperatures ranging between 260 °C and 274 °C (500 °F and 525 °F). This tool requires about 10 to 12 minutes to preheat. One side of the tool is used to heat the inside of the fitting; the other side of the tool is used to heat the outside of the tube. Before heating the pieces, a depth gage is placed on one end of the tube to act as a guide for the cold ring, which is attached flush against the depth gage, and left there during the heating process. The cold ring prevents heat transfer along the length of the tube, and acts as a guide, allowing the fitting to be slid over the tube to the correct distance. Both the tube end and fitting are pushed into their respective socket faces, onto the heating tool, and held there for a specified heating time. Fusion heating times are shown in table 8. These manufacturer specified heating times are between 5 and 18 seconds, depending on the size of the tube [40]. After the specified heating time, the fitting and tube are removed from the heating tool and quickly pushed together, without twisting, until the cold ring is in contact with the fitting edge. They are held firmly together for 30 seconds. No stress should be placed on the joint for 20 minutes, after which, the joints may be pressure tested.

Table 8.
PB Sprinkler Tube Size
vs. Fusion Heating Time

Nominal Size* DN (mm)	Heating Time (sec)
20	5-7
25	8-10
32	10-12
40	12-15
50	12-18[5]

* Refer to table 5 for the corresponding nominal pipe sizes in inches.

The crimping method requires no heating tools, only a brass or copper fitting, a copper crimp ring, and a motorized or hand held crimping tool. This method is currently available only for the DN25 (1.0 in) size tube. Once the tube is cut to the correct length, the brass ring is slid several centimeters onto the tube. Next, the fitting is placed inside the tube. The copper ring is then slid over the tube and fitting connection. The crimping tool is positioned over the ring and activated, crimping the tube to the fitting. When the copper ring is crimped onto the PB tube and fitting, the plastic tube material flows into the grooves of the brass fitting under the crimp, creating a solid joint.

7.0 HANGER AND BRACING CONSIDERATIONS

7.1 Support Spacing Requirements—All Pipe

Fire sprinkler system hangers and braces must be spaced according to the pipe manufacturer's recommendations or in accordance with NFPA to prevent excessive sagging. The type of hanger or brace used is equally important. NFPA 13 and NFPA 13R require that hangers be designed to support five times the weight of the water-filled sprinkler pipe plus 113 kg (250 lb) at each point of piping support. Because the dynamic loads and forces are considerably lower than those typically experienced in a 13 or 13R system, NFPA 13D requires only that supports be recognized in local plumbing codes for the piping materials. In all cases, special listed pipe must be supported in accordance with its listing.

Spacing requirements for sprinkler pipe hangers, adapted from NFPA 13, table 4-6.2.2.1, range between 3.7 m and 4.6 m (12.0 ft and 15.0 ft). These requirements are presented in table 9. NFPA 13 also states that the maximum distance between hangers for CPVC and PB pipe shall be modified as specified in the individual product listings [3]. The beam strength associated with steel pipe allows for larger distances between supports than are allowed with any other type of sprinkler piping material. Because of the lack of material between the inside diameter and the root diameter of the thread, hangers must be spaced closer together for threaded lightwall steel pipe. Copper is slightly more flexible than steel. As such, the distance allowed between hangers in a copper tube system is less than that of steel but more than that

[5] For the DN50 (2.0 in) tube, heat for 15 to 18 seconds if the temperature is below 0 °C (32 °F).

of CPVC or PB. Threaded lightwall steel pipe DN50 (2.0 in) or larger requires the same hanger spacing as copper tube.

Many companies supply hangers and braces specifically designed for non-metallic sprinkler pipe. The recommended hanger load bearing surface (minimum hanger width) for CPVC is at least 12.7 mm (0.50 in). Any less surface area might overstress the pipe, increasing the probability of failure. "Most hangers designed for metal pipe are suitable for [plastic] pipe.... Hangers with sufficient load-bearing surface shall be selected based on pipe size, i.e., 38.1 mm (1.50 in) hangers for DN40 (1.50 in) pipe. The hanger shall not have rough or sharp edges which come in contact with the pipe" [14]. Manufacturer recommendations concerning the support dimensions should be followed.

Adequate bracing at the sprinkler heads is important in CPVC and PB fire sprinkler system installations. Being a flexible material, the pipe is particularly susceptible to a reaction force from the water release during a sprinkler head activation. PB sprinkler tube is sometimes sent from the shop to the installation site with pre-attached bracing at the sprinkler heads on the vertical drops. It is therefore more difficult to omit the bracing requirements during an installation. The manufacturer's requirements for bracing at or near the sprinkler head should be followed.

Table 9.
Nominal Pipe Size vs. Support Spacing Requirements

Sprinkler Material	Nominal Size* (mm)						
	DN20	DN25	DN32	DN40	DN50	DN65	DN80
	Support Spacing Requirements* (m)						
Steel Pipe Except Threaded Lightwall	N/A	3.7	3.7	4.6	4.6	4.6	4.6
Threaded Lightwall Steel Pipe	N/A	3.7	3.7	3.7	3.7	3.7	3.7
Copper Tube	2.4	2.4	3.0	3.0	3.7	3.7	3.7
CPVC	1.7	1.8	2.0	2.1	2.4	2.7	3.0
Polybutylene (CTS)	0.9	1.0	1.2	1.3	2.3	N/A	N/A

*Multiply the values in the table by 3.2801 ft/m to obtain the support spacing requirements in feet.
Refer to table 5 for the corresponding nominal pipe sizes in inches.

7.2 Permissible Bending and Deflection—CPVC

Because CPVC is flexible, it can be deflected around obstacles more readily than its metal counterparts. Adequate care must be exercised, however, so that excessive deflection does not occur, potentially damaging the pipe. Deflection of the CPVC pipe may occur in two ways: bending and snaking. Tables 10 and 11, adapted from manufacturer supplied data, using ambient temperatures of 23.0 °C (73.0 °F), show values for the allowable deflection using several run lengths [41]. If the allowable deflection exceeds the values shown in the tables, failure may occur, rendering the fire sprinkler system ineffective.

Table 10.
CPVC Pipe Size* vs. Permissible Bending Deflection

Nominal Size (mm)	Length of Run (m)							
	0.61	1.52	2.13	3.05	3.66	4.57	5.18	6.10
	Pipe Deflection (mm)							
DN20	33.0	198	391	795	1146	1791	2301	3185
DN25	25.4	160	312	635	914	1430	1836	2543
DN32	20.3	127	246	503	724	1133	1460	2014
DN40	17.8	109	216	439	632	991	1273	1760
DN50	15.2	88.9	173	353	508	792	1016	1407
DN65	12.7	73.7	142	290	419	655	841	1163
DN80	10.2	61.0	117	239	343	538	691	955

*Multiply the values in the table by 0.03937 in/mm to obtain the permissible bending deflection values in inches.
Multiply the values in the table by 3.2801 ft/m to obtain the length of run in feet.
Refer to table 5 for the corresponding nominal pipe sizes in inches.

Table 11.
CPVC Pipe Size vs. Permissible Snaking Deflection

Nominal Size (mm)	Length of Run (m)							
	0.61	1.52	2.13	3.05	3.66	4.57	5.18	6.10
	Pipe Deflection (mm)							
DN20	7.6	50.8	96.5	198	287	447	574	795
DN25	76	40.6	78.7	160	229	358	459	635
DN32	51	30.5	61.0	127	180	284	363	503
DN40	51	27.9	53.3	109	157	246	318	439
DN50	25	22.9	43.2	88.9	127	198	254	353
DN65	25	17.8	35.6	73.7	104	163	211	300
DN80	25	15.2	30.5	61.0	86.4	135	173	239

*Multiply the values in the table by 0.03937 in/mm to obtain the permissible snaking deflection values in inches.
Multiply the values in the table by 3.2801 ft/m to obtain the length of run in feet.
Refer to table 5 for the corresponding nominal pipe sizes in inches.

7.3 Minimum Bending Radius—PB

Since PB tube is very flexible, it is more easily bent around obstacles than any other fire sprinkler system pipe material. Care must be exercised, however, so that excessive bending does not occur, potentially damaging the tube. The manufacturer-recommended bending radii as a function of tube size are seen in table 12 [42].

Table 12.
PB Tube Size vs. Minimum Bending Radius

Nominal Size DN (mm)	Bending Radius (mm)
20	279
25	356
32	432
40	508
50	660

* Multiply the mm values by 0.03937 in/mm to obtain the bending radius in inches.
Refer to table 5 for the corresponding nominal pipe sizes in inches.

7.4 Compensation for Thermal Expansion--CPVC and PB

The CPVC manufacturer states that for every 13.9 °C (25.0 °F) temperature increase, a 15.2 m (50.0 ft) section of the pipe will expand 12.7 mm (0.50 in). Expansion loops, offsets and change of direction in the sprinkler piping systems, shown in figures 3, 4, and 5, are methods used to compensate for the CPVC pipe expansion when subjected to varying temperatures. Expansion and contraction changes may cause a problem in long straight runs of pipe; these compensation methods prevent long straight runs of pipe, and thus their associated expansion and contraction problems. The expansion loop method involves shaping the pipe into a "U", preventing a long straight run of pipe. The offset method prevents the long runs of straight pipe by changing the pipe direction twice, so that the original and final directions are the same. Lastly, the change of direction method changes the pipe direction once by 90°. Each method of compensating for thermal expansion requires the use of additional braces. It is important to estimate the range of temperature the CPVC fire sprinkler pipe is expected to experience under normal operating conditions, and install the system accordingly. The manufacturer supplies a list of recommended loop lengths, which vary according to expected temperature ranges [28].

PB will expand and contract depending on the ambient temperature. The manufacturer states that a 30.5 m (100 ft) section of the tube will expand 22.0 mm (0.85 in) for every 5.6 °C (10.0 °F) increase in temperature. Expansion loops, offsets and change of direction allowances are not recommend by the manufacturer. Instead, to compensate for thermal expansion and contraction, snaking the tube, as shown in figure 2, is the preferred alternative. This simply involves leaving slack in the tube during installation, rather than pulling it taut.

8.0 SYSTEM DESIGN (HYDRAULIC CALCULATIONS)

Hydraulic calculations are performed for a fire sprinkler system to determine the pressure and flow requirements at the base of the sprinkler riser. This aids in the determination of the adequacy of the water supply to the sprinkler system. To hydraulically calculate a fire sprinkler system, one must determine the pressure losses through each pipe segment, straight lengths of pipe as well as fittings and valves.

NFPA 13 states that the pipe friction losses shall be determined on the basis of the Hazen-Williams formula [3],

$$P_m = 6.05 \, x \frac{Q_m^{1.85}}{C^{1.85} \, d_m^{4.87}} \, x \, 10^5$$

where:

P_m = frictional resistance in bars per meter of pipe
Q_m = flow in ℓ/min
d_m = actual internal diameter in mm
C = friction loss coefficient

In English units

$$p = \frac{4.52 \, Q^{1.85}}{C^{1.85} \, d^{4.87}}$$

where:

p = frictional resistance in pounds pressure per square inch per foot of pipe
Q = gallons per minute flowing
d = actual internal diameter of pipe in inches
C = the friction loss coefficient

The Hazen-Williams formula is the most common empirical formula used to determine the relationships between fluid flow, friction loss, and available pressure when designing a fire sprinkler system [1]. The formula is dependent upon the relationship between the type of pipe (the C factor), the pipe diameter, and the given flow. The C factor is a measure of the relative roughness of the pipe interior (smoothness of the pipe interior wall). A higher C factor corresponds to a smoother pipe interior wall. The smoother the interior pipe walls, the lower the pressure loss through the pipe.

Table 13, adapted from NFPA 13, table 6-4.4.5, shows the C factors for the piping materials discussed in this report.

Table 13.
Hazen-Williams C Values

Hazen-Williams C Values - NFPA Pipe or Tube	C Factor
Black Steel (dry systems including preaction)	100
Black Steel (wet systems including deluge)	120
Galvanized (all)	120
Plastic (listed)—all	150
Copper Tube	150

NFPA states that the C values for steel pipe tend to decrease with time. The C value given in the table is the "design" C value representing aged pipe (pre-adjusted for some corrosion and scale build-up of the pipe). If pipe were in its original pristine state, it would have a somewhat higher C value. This difference in C value is termed the upscale factor. NFPA gives an upscale factor for steel of 16 percent. NFPA gives an upscale factor of copper tube and all plastic materials of 0 percent. This may be adequate for design purposes, however, all pipe subject to corrosion, scale build-up and/or sedimentation will show some decrease in the value of the C factor over time. Corrosion, scale build-up, and sedimentation are functions of the water supply properties; they are difficult to predict without knowledge of those properties. If the water quality is poor, the rate of deterioration of the pipe will occur at a rate faster than that normally encountered with better quality water supplies. In these cases, further C factor penalties should be applied.

The pressure loss through a segment of pipe is calculated using the Hazen-Williams formula given above multiplied by the length of pipe in the segment. The length of pipe is the length of straight pipe plus some "equivalent pipe length" for valves and fittings. Equivalent pipe lengths are a function of the fitting geometry. This fitting equivalent length is determined by measuring the pressure drop through the fitting. This pressure drop value is compared to the length of straight pipe which would reduce the water pressure by an equal amount.

Table 14, extracted from NFPA 13 table 6-4.3.1, and tables 15, 16, 17, and 18 of this report, obtained from manufacturer supplied data, show values for fitting equivalent lengths for steel, copper, CPVC, and PB sprinkler pipe [3, 43,14,34]. Tables 15, 16, 17, and 18 of this report are presented because NFPA 13 suggests that table 6-4.3.1 of the standard shall be used unless manufacturer's test data indicate that other factors are appropriate.

Table 14.
Steel Fitting Equivalent Pipe Lengths* (m)

Fitting Type	Nominal Size (mm)						
	DN20	DN25	DN32	DN40	DN50	DN65	DN80
Elbow 90	0.61	0.61	0.91	1.22	1.52	1.83	2.13
Tee or Cross (Flow Turned 90)	0.91	1.52	1.83	2.44	3.05	3.66	4.57

* Multiply the values in the table by 3.2801 ft/m to obtain the fitting equivalent lengths in feet.
Refer to table 5 for the corresponding nominal pipe sizes in inches.

Table 15.
Copper Fitting Equivalent Tube Lengths* (m)

Fitting Type	Nominal Size (mm)						
	DN20	DN25	DN32	DN40	DN50	DN65	DN80
Tee Branch	0.61	0.61	0.91	1.07	1.52	1.83	2.29
Tee Run	0.15	0.15	0.31	0.30	0.30	0.46	0.46
Elbow 90°	0.30	0.61	0.61	0.76	1.07	1.22	1.52
Coupling	0.15	0.15	0.30	0.30	0.30	0.46	0.46

*Multiply the values in the table by 3.2801 ft/m to obtain the fitting equivalent lengths in feet.
Refer to table 5 for the corresponding nominal pipe sizes in inches.

Table 16.
CPVC Fitting Equivalent Pipe Lengths* (m)

Fitting Type	Nominal Size (mm)						
	DN20	DN25	DN32	DN40	DN50	DN65	DN80
Tee Branch	0.91	1.52	1.83	2.44	3.05	3.66	4.57
Tee Run	0.30	0.30	0.30	0.30	0.30	0.61	0.61
Elbow	2.13	2.13	2.44	2.74	3.35	3.66	3.96
Coupling	0.30	0.30	0.30	0.30	0.30	0.61	0.61

*Multiply the values in the table by 3.2801 ft/m to obtain the fitting equivalent lengths in feet.
Refer to table 5 for the corresponding nominal pipe sizes in inches.

Table 17.
PB Fusion Method Fitting Equivalent Tube Lengths* (m)

Fitting Type	Nominal Size (mm)				
	DN20	DN25	DN32	DN40	DN50
Tee Branch	1.22	1.52	2.44	2.44	3.05
Tee Run	0.30	0.30	0.61	0.61	0.61
Elbow 90°	0.91	.914	1.52	1.52	1.83
Coupling	0.30	0.30	0.30	0.30	0.30

*Multiply the values in the table by 3.2801 ft/m to obtain the fitting equivalent lengths in feet.
Refer to table 5 for the corresponding nominal pipe sizes in inches.

Table 18.
PB Crimping Method Fitting Equivalent Tube Lengths* for the DN25 Nominal Size Tube

Fitting Type	Fitting Equivalent Length (m)
Tee Branch	5.15
Tee Run	1.22
Elbow	1.52
Coupling	1.13

*Multiply the values in the table by 3.2801 ft/m to obtain the fitting equivalent lengths in feet.
Refer to table 5 for the corresponding nominal pipe sizes in inches.

9.0 ECONOMICS

The cost of a fire sprinkler system includes the cost of materials, installation, and maintenance. Cost of the materials include the pipe, fittings, hangers, and braces. Installation costs take into account labor rates, ease of connection of the pipe, new installation or retrofit, and pressure testing of the pipe upon completion of the system.

Material costs for system parts vary. One comparison between CPVC and copper [44], shows the cost of the copper tube as 38 percent higher than the CPVC pipe. The same comparison, however, shows the cost of CPVC 90° elbows and tees as 49 percent to 72 percent more expensive than copper. The comparison study was done for a single-family home and shows that the overall material cost for the CPVC is "a few dollars less than the comparable copper system" [44].

Another cost comparison [45], compares lightwall steel to CPVC for a 170 sprinkler head installation for a typical hotel floor, retrofit project. This study shows the CPVC pipe as more expensive than the lightwall steel with higher costs for the steel main fittings and lower costs for the steel line fittings. The cost of the supports for the plastic system is twice that of the steel system [45]. Again, however, total material costs are similar (within 10 percent).

Installation costs are of significance when considering the economics of a particular job. Factors such as the number of required joints, labor rates, ease of pipe connection, new installation or retrofit, and waiting time before pressure testing of the system may begin, all effect the economics of an installation. Annealed copper, CPVC, and PB fire sprinkler systems require more hangers and braces than a steel pipe system, which is added cost in terms of more supports and longer labor time to install them. However, the same flexibility enjoyed by the annealed copper, CPVC, and PB fire sprinkler pipe, which mandates the added supports, allows the pipe to be bent around obstacles. This eliminates the extra fittings required with the more rigid metal system, saving material costs and installation time.

Based on a limited number of examples, it was seen that the cost of each system may be very similar (within 10 percent), depending on whether the installation is for new construction or retrofit, installer choice, quantity of pipe and fittings required, and myriad other variables. These other variables may include the contractor's relationship with the supplier, the contractor's past experience with specific systems, and the quantity of jobs being performed for the customer. The economics of a job depend heavily on these and countless other factors.

10.0 MAINTENANCE

Integrity and reliability of a fire sprinkler system are heavily dependent on how well a particular system is maintained. A fire sprinkler system may experience damage in several ways, resulting from human actions and natural causes. For example, sprinkler systems are often installed early in the construction process. Other trades, such as electrical and plumbing, often work in the same spaces occupied by the sprinkler pipes, creating the possibility of damage to the sprinkler system. A system may also experience damage through human action even after the building construction is complete. For example, workers sometimes install television cables through overhead spaces that fire sprinkler pipe occupies.

In order to detect problems before a system failure occurs, NFPA 25, "Standard for the Inspection, Testing and Maintenance of Water-Based Fire Protection Systems" [46], should be followed. This standard requires annual inspections of fire sprinkler system. These inspections involve a visual check to see that the piping is free of mechanical damage, leaking, corrosion, and misalignment, regardless of the material used.

11.0 SUMMARY

There are a variety of fire sprinkler piping materials to select from when specifying, designing, or installing an automatic fire sprinkler system. Selection of a pipe material can be based on many factors, some of which are a function of pipe material itself, while others depend on the application and installation conditions. Key variables to consider are the pipe material properties, degradation of the pipe due to corrosion and/or heat, occupancy classifications, specific installation requirements, methods for joining the pipe, system design and hydraulic calculations, hanger and bracing considerations, economics, and maintenance. Each pipe system has advantages and disadvantages with respect to these variables; no one pipe system is the optimum choice for all installations. Table 19 offers a brief overview of the characteristics and uses of the various fire sprinkler pipe materials.

Steel and copper fire sprinkler piping have higher mechanical strength and much higher melting points than CPVC and PB pipe. They are less susceptible to damage from dropping or stepping on the pipe, UV exposure, heat, or damage from other work ongoing near the pipe (scratches or gauges). CPVC and PB plastic sprinkler pipes, however, are lighter weight and more easily routed around objects in the field, making installation procedures easier. All four materials, steel, copper, CPVC, and PB are specified for use in NFPA 13 light hazard, NFPA 13D and NFPA 13R. CPVC and PB sprinkler pipe systems, however, are subjected to certain requirements\limitations governing where and how they can be installed. These limitations specify among other things, protection for the pipe from the heat of a fire, a maximum ambient temperature, and specific operation temperatures of the installed sprinklers. They are not to be used in dry systems.

CPVC and PB pipe are not susceptible to corrosion and scale build-up as are steel and copper fire sprinkler pipe. All piping materials are subject to sedimentation of debris in the water supply. Size DN20 (0.75 in) pipe may be used in copper, CPVC, and PB pipe systems. Larger sizes are required when using steel pipe fire sprinkler systems. The largest size CPVC and PB sprinkler pipes available are DN80 and DN50, respectively, while much larger sizes of the steel and copper pipes are available.

CPVC and PB sprinkler pipes are joined to fittings with relative ease. Training procedures for installers of CPVC and PB sprinkler pipe systems are relatively short and straightforward. Hangers are required more frequently with these systems, while metal systems generally require fewer supports because of the associated beam strength. Economics is an important factor when considering piping systems. The prices vary depending on several factors, including installer experience, size of sprinklered area, available material supply, and local codes.

Because many piping options are now available for use in fire sprinkler systems, many factors must be considered when choosing specific piping. Since each system has advantages and disadvantages, the choice is heavily dependent on the specific application.

Table 19.
Summation of Variables Affecting Fire Sprinkler Pipe Selection

Property	Pipe or Tube Type				
	Steel Sch. 40	Typical lightwall steel	Copper Type M	CPVC SDR 13.5	PB SDR 11
color	black	silver	copper	bright orange	grey
weight of the DN25 (1 in) size (kg/m)	2.5	1.8	0.7	0.4	0.2
melting point (MP) or heat distortion temperature (HDT)	(MP) 1427-1538°C (2600 - 2800 °F)	(MP)1427-1538 °C (2600 - 2800 °F)	(MP) 1082 °C (1980 °F)	(HDT) 103°C (217 °F)	(MP) 122-126 °C (252 -259 °F)
damage susceptibility	low	low	low	high with UV exposure and impacts	high with UV exposure and impacts
corrosion susceptibility/ design C factor	high/ 120	high/ 120	moderate/ 150	low/ 150	low/ 150
occupancy classification— NFPA standards	not limited	not limited	not limited	NFPA 13 light hazard, 13D, 13R, concealed and restricted exposure NFPA 90A	NFPA 13 light hazard, 13D, and 13R concealed only
maximum ambient temperature	not limited	not limited	not limited	66 °C (150 °F)	49 °C (120 °F)
flexibility/hanger spacing for the DN25 (1 in) size (m)	not flexible/ 3.7	not flexible/ 3.7	slightly flexible/ 2.4	flexible/ 1.8	very flexible/ 1.0
expansion concerns/ solutions	negligible	negligible	negligible	yes/ offsets, direction changes, loops	yes/ snaking pipe
fitting type	threaded grooved flanged plain-type	threaded grooved flanged plain-type	soldering brazing grooved	primer/solvent cement	heat fusion crimping
compatible antifreeze	not limited*	not limited*	not limited*	glycerine*	ethylene glycol propylene glycol methanol glycerine*

*NFPA recommends that only antifreeze solutions of glycerine or propylene glycol be used when the sprinkler system is connected to potable water.

12.0 ACKNOWLEDGEMENTS

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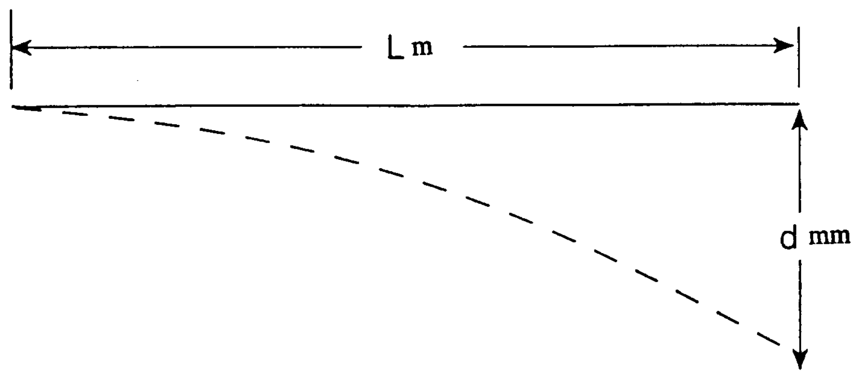

Figure 1. CPVC Bending.

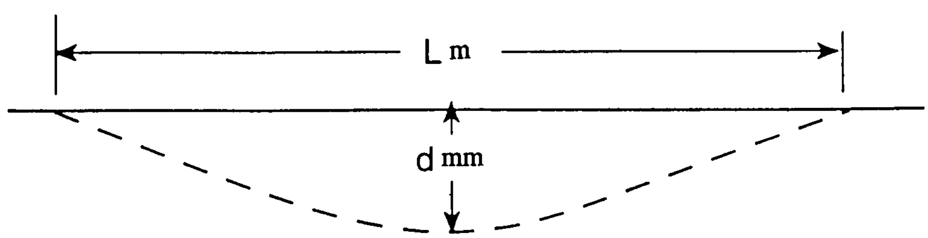

Figure 2. CPVC Snaking.

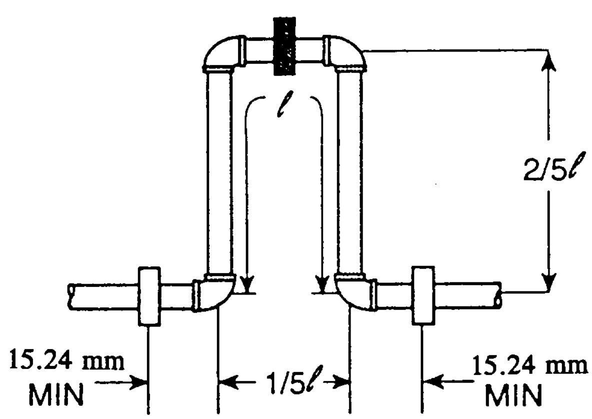

Figure 3. Expansion Loop.

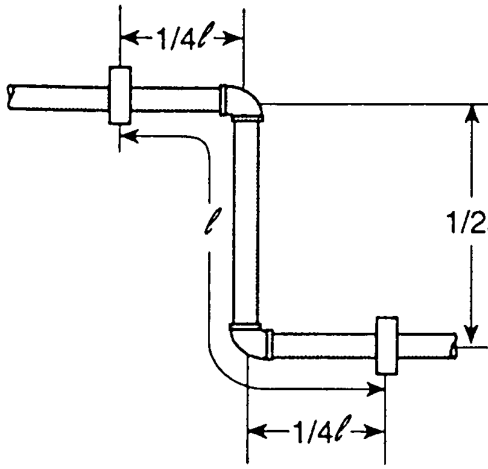

Figure 4. Offset.

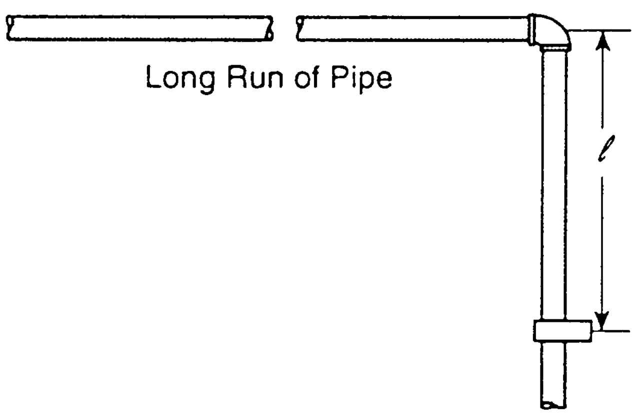

Figure 5. Change of Direction.