Plastic Pipe and Fire Safety

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1. INTRODUCTION

Plumbing piping based on thermoplastic resins, such as ABS, CPVC, PE and PVC, has been commonly used in construction in the United States and Europe for many years. The technical literature on the properties of plastic piping is extensive, both on the general properties affecting their safe and efficient use, and its properties in the event of a fire. In contrast to the metal plumbing piping products used in buildings before the development of plastic piping systems, the fire performance of plastic pipe has been the subject of extensive contemporary research and development, as well as regulatory activity.

Over the years, general fire safety questions have been discussed in regulatory forums that specifically targeted applications of plastic piping products in buildings. Such discussions have occurred at local, county, and state levels, as well as in nationwide forums sponsored by model code and standards promulgators--the ICC (the International Code Consortium), BOCA (Building Officials and Code Administrators), ICBO (the International Conference of Building Officials), and SBCCI (the Standard Building Codes Conference International). The National Fire Protection Association (NFPA), ANSI (American National Standards Institute), the American Society for Testing Materials (ASTM), and the International Association of Plumbing & Mechanical Officials (IAPMO) have also taken part in these discussions.

In the 1970's the U.S Department of Housing and Urban Development (HUD) sponsored benchmark studies to evaluate the working properties of plastic pipe[1]. These studies were conducted primarily to ensure that plastic pipe installed in federally funded housing projects met the HUD Minimum Property Standards. This same HUD program also studied the fire safety aspects of plastic pipe use [2].

Subsequent research has focused on the impact of plastic pipe installations on life safety in portions of buildings that contain either archaic metal piping or contemporary plastic piping materials remote from a given fire incident. These analyses typically used the existing fire resistance properties of buildings as starting points [3].

As the use of plastic pipe gained in popularity, research, technological advances, and fire codes evolved apace, insuring that a given plastic piping product in a given occupancy was safe. A good example of this evolution can be found by comparing the California State Fire Marshal's 1980 review of plastic pipe and fire safety with later works on the same subject [4]. That review concluded that use of plastic piping products in low-rise and residential or multifamily buildings did not pose a hazard. However, it also concluded that - at that time - use of plastic piping systems in more complex structures, such as high-rise buildings and multiple unit apartments required additional research to demonstrate acceptable levels of fire safety

Today, U.S. regulations and model building codes do not restrict the use of plastic pipe by occupancy type or type of construction. Implicit in the provision is that appropriate attention must be paid to design and installation detailing, especially plastic pipe use in fire resistive buildings. This article will review the development of the technical applications and regulatory standards referred to above, the impact of regulations and fire safety issues on plastic pipe use to date, and the future of plastic pipe applications in construction.

2. PLASTIC PIPE AND FIRE ENDURANCE

How does the inclusion of plastic pipe in the construction of *any* room impact the life safety of the occupants of that room when a fire starts?" In order to answer that question, consider what happens if plastic pipe is present and a fire begins.

Fires generally begin with the ignition of a single item. If secondary ignition occurs (usually furnishings or light combustibles), the fire may grow and spread to some degree. Most rooms do not have exposed plastic pipe, except perhaps as a trap under a sink. In general, plastic pipe is installed behind walls or ceiling lining materials that form the "lining" or "boundary" of the room. Typically such materials are able to resist a growing fire for 15 minutes or more. [5]

Therefore, plastic pipe installed <u>behind</u> such room linings, while combustible, does not present an increased life safety threat to the room of origin's occupants. ASTM E-119 fire testing and hose stream tests (Figs. 1-5) and post-fire evaluations of buildings that included plastic pipe in their construction demonstrate that plastic-piping materials will generally either burn away and char at the wall line (Fig.6) or melt and drop in a wall cavity.

The early period of any fire, or a fire that never grows sufficiently to extend beyond room boundaries, is characterized as the *pre-flashover fire growth* period; such events are called pre-flashover fires. These events do not threaten the lives of room inhabitants, nor threaten the integrity of the boundaries of the affected room. Likewise, *pre-flashover* fires do not threaten the well being of people elsewhere in an affected building. Given the right combination of fuel, ventilation, and lack of intervention, however, fully involved, *post-flashover* fires may follow a *pre-flashover* period. It is the destructive spread of fire by-products such as smoke and hot gases (sometimes referred to as "convective spread") that may occur in the *post-flashover* period of fires that may threaten people in other parts of the building

At what point will plastic piping materials burn during a room fire incident? Since fires often start in kitchens, does the presence of small amounts of exposed plastic pipe, such a plumbing trap under a sink, increase the level of fire hazard? Based on the review of fire incident databases, including those maintained by the NFPA, the answer is no. This review found that in the U.S. during the last 40 to 50 years, no unique hazard or relationship has been identified or demonstrated that would link this class of products to unusual fire ignition or fire spread [6].

Figure 1

Private Residence, San Jose, CA. Post-fire with roof burned off of garage area. Arrow shows ABS plastic DWV stack.

Figure 2.

Same location as preceding; close-up of DWV stack with calcined wallboard removed.

Figure 3

Fire damaged townhouse complex, San Diego, CA.

Figure 4

Vent stack at San Diego townhouse complex, post-fire.

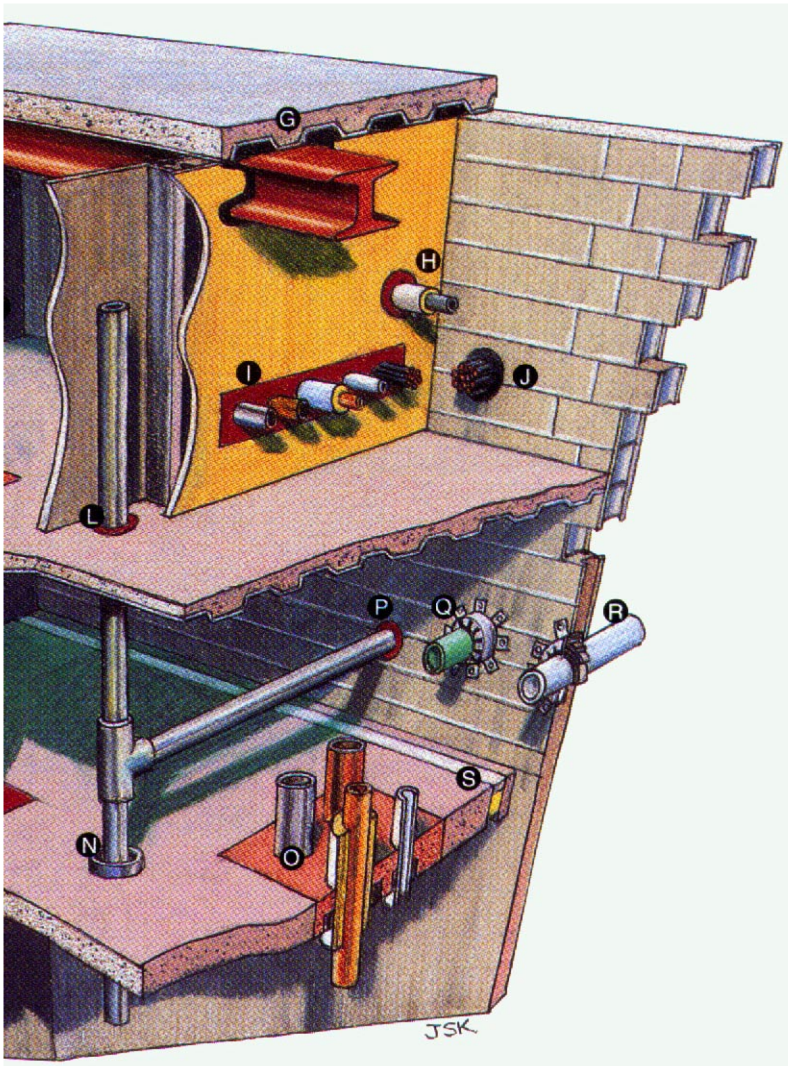
Figure 5.

DWV stack. ABS remains in concealed spaces. Note charring of adjacent wood framing and sheathing.

Figure 6.

Hose stream specimen, PVC DWV following 30 minute E-119 exposure.

Figure 7



Typical fire resistive assembly configurations in building (courtesy 3M).

Similarly, current combustion toxicity data linking life safety with the use of foreseeable amounts of plastic pipe in buildings predicts no potential hazard to room or building occupants, providing that code-mandated installation criteria has been followed. This is consistent with data published from the early 1980s through 1987 [7,8] considered by the NFPA Toxicity Advisory Committee in reviewing applications of plastic tube and conduit for use in electrical installations. These observations are also consistent with information available at that time to model building code agencies and state and federal bodies regulating the use of plastic pipe.

Having determined that there is little or no danger to individuals in a room where plastic pipe may have been installed and a fire occurs, a more complex question needs to be considered: How does the addition of plastic pipe affect the life safety of occupants in other areas of the building and the fire performance of the effected building in general? To answer this question, the impact of plastic pipe installation on building fire endurance/fire resistance needs to be addressed. Specifically, how is the fire resistance of building elements, such as walls, floors, ceilings, shaft ways, and structural systems, affected during an intense, fully developed, post-flashover fire[a]. A briefly review related to fire resistive plastic pipe applications in fire resistive or fire endurance rated structures is found below.

Fire-resistive construction techniques are incorporated in building designs to withstand post-flashover fire exposure conditions for specific periods of time without allowing fire to spread from initially affected areas. A simple example of fire-resistive construction is found in the wall separating an attached garage from the living spaces in a private dwelling. Here, fire-rated gypsum wallboard and specific construction features, such as solid core wood door in a tight fitting frame, are the minimum requirements to prevent a fire that starts in a garage from spreading too rapidly into the occupied dwelling space.

More complex fire resistive designs and construction are found in high-rise buildings where fire endurance rated concrete slabs for floor/ceilings and walls and/or gypsum-based chase or shaft walls are commonly used to separate critical areas. In all cases, the design and detailing of these assemblies must include provisions for the safe distribution of utilities and other service

[a] The following discussions consider only buildings of fire resistive construction, i.e., construction designed to resist a fire of a given intensity for a given period without allowing that fire to spread. Such buildings are designed and built to incorporate a specific level of fire endurance using fire resistive construction features. Such features are not found in non-rated construction, i.e., in most single-family dwellings, where the cost of including extended fire endurance is not necessary to protect the life safety of occupants.

assemblies traversing across sections, such as floor-to-floor, unit-to-unit, shaft-to-unit, etc. These same assemblies, which routinely involve plumbing, electrical, and HVAC elements, must also preserve the specific fire safety design features that were part of the original, basic wall design. Such wall designs may be considered generic, but once the utilities needed for a specific project are called out, the final design will become project specific.

The most common way to describe the performance of fire-resistive construction is through specification of an hourly rating. The hourly rating is used to describe anticipated fire endurance of specific fire-resistive elements, such as floor slabs, slab walls, and chase or shaft constructions. These assemblies are characterized by their ability to resist a standard fire determined by the ASTM E-119 time-temperature curve, with associated pass/fail criteria for a specific fire endurance period.

Given the wide variety of construction features found in fire endurance rated buildings, this review will concentrate on walls or floor/ceiling assemblies, as these are the most commonly associated with piping elements. In terms of fire rated walls and floor/ceilings, these may be built as monolithic assemblies composed of concrete slabs only, or they may include assemblies containing cavities. The latter occur when metal or wood studs or joists form the structural system and cladding, and include inorganic materials like gypsum wallboard or plaster.

There are many variants of these systems, for example, when concealed spaces and/or hung ceilings, shaft, or chase walls are included in a design. The latter occur when an enclosed space is deeper than a normal wall and may include single or multiple fire resistive membranes that are penetrated by piping. Walls with only one membrane that is penetrated (a cavity wall of floor/ceiling assembly) is characterized as a *membrane penetration* as opposed to a *through penetration.*

Proper execution of fire endurance rated design features is important to maintain the integrity of all fire resistive wall designs, such as those found in the Gypsum Association Handbook [9]. This is especially true when assemblies are modified by the installation of plastic piping. Figure 7 shows examples of typical fire-resistive assembly configurations.

3. PLASTIC PIPE IN FIRE-RATED BUILDINGS.

The plastic piping systems of greatest concern in fire rated buildings are, by far, those for drain, waste, and vent (DWV) functions and drainage of rainwater applications. These pipes, which transport waste and gases through a building, are hollow and combustible. Therefore without appropriate installation and mitigation their presence could create a natural weakness in a building's fire rated construction features. Potentially, smoke, hot gases, and products of combustion could pass through these pipes if the fire resistance ability of their openings is not properly addressed.

Other plastic piping systems, such as water supply piping used to transport hot and cold running water from one part of building to another, and sprinkler piping for fire suppression occur in fire resistive assemblies. Plastic pipe applications for process piping are also common, especially for movement of chilled water and (high purity) chemicals in hazardous occupancies, such as semiconductor fabrication sites.

The classes of piping materials found in the applications described above are differentiated from those installed in DWV applications because those pipes contain a liquid that enhances fire endurance during fire incidents or fire exposure. Such piping applications are not vented and are generally smaller in diameter than in DWV applications. The use of such smaller diameter sizes reduces the risk of failure in the event of a fire. It also reduces the relative size of the voids that may form if they do fail.

As discussed above, the term "through penetration" is generally taken to mean an opening that transverses an entire fire-resistive assembly. Such openings are usually made for the penetration of piping, electrical, or other building services or possibly for joints (e.g., earthquake joints or construction joints) in concrete slab assemblies. How are such openings characterized and, most importantly, how are these openings treated to prevent the unwanted spread of fire?

Membrane penetrations are a close relative to through penetrations, but differ in that they encompass openings in fire resistive membranes. Such penetrations *do not* traverse the <u>entire</u> fire-resistive assembly. Rather, only a portion of the assembly is transversed. Examples of membrane penetrations include single-sided plumbing penetrations, such as those under sinks, and openings created by electrical boxes in walls or ceilings for outlets, switches, or lighting applications.

To ensure that these penetrations maintain their integrity in the event of a fire, a through penetration or membrane penetration firestop assembly may be used. Either generic firestops or proprietary components requiring careful installation may be used. Generic fire-resistant stopping materials, such as grout or thermal insulation, can also be used to insure that the performance of a penetration is as good as, or better, than that of the original fire endurance rated assembly in which it is installed. Thus, by firestopping a through or membrane penetration with appropriate, *approved* materials it is assumed that that penetration will have the same fire resistance—resistance to destruction by the standard design fire - as the unpenetrated parent assembly. The term “approved” refers to approval for use by an Authority Having Jurisdiction (AHJ). Figure 8 shows examples of fire resistive assemblies and the different types of components found in such assemblies.

Figure 8

Typical plastic DWV components found in assemblies in fire resistive construction.

In most cases materials used to firestop penetrations in a fire-resistive assembly will have been tested by, labeled (describing the test conducted), and listed with an independent third party testing laboratory. Installation parameters for a given product or system in a particular application can be found in these listing documents or books. This information assists the AHJ in deciding whether or not to approve the materials used in a given installation.

Another factor relevant to plastic pipe installation in air handling spaces in buildings is flamespread performance. Flamespread is determined using the ASTM E-84 “Steiner Tunnel Test” and must be considered when plastic pipe is installed in concealed spaces—used for air handling—between a suspended ceiling and a structural floor. These restrictions are based on the possible exposure of HVAC return air to plastic piping materials. If such piping installations show flamespread performance greater than 25 and smoke development greater than 50, a life safety hazard may exist. Exact regulations governing such uses are found in model mechanical code sections listing components allowed in such plenum constructions, as well as the NFPA 90A standard[b].

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[b] Certain air handling applications and functions are actually approved for plastic pipe such as those found in section 1901.1.2 of the 1998 *International Residential Code – 1& 2 Family Code.* That section permits the use of plastic pipe for air handling if service temperatures do not exceed 150^{o}F (66^{o}C).

4. PLASTIC PIPE: EVOLUTION OF REGULATIONS

Research on the performance of plastic pipe in air handling plenum spaces has shown that, with the exception of CPVC sprinkler piping, plastic pipe must be boxed-in with gypsum wallboard or covered with fiberglass insulation [10]. Such installation methodologies are consistent with model mechanical codes.

Regulations governing the use of plastic piping in fire resistive construction developed in concert with the new fire testing technology and resulting data. Fire testing of assemblies including plastic piping systems began in the 1960's and 1970's. In the U.S. at that time, model code requirements used to regulate the installation of plastic pipe in fire-resistive construction were based on application of the ASTM E-119 test standard, "Fire Tests of Building Construction and Materials".[c]. Complete, full sized fire resistive assemblies with plastic pipe installed were tested to meet the E-119 requirements. Test results for plumbed assemblies were frequently compared to those same results for a given assembly tested *without* plastic pipe to determine the impact of the piping installations on assembly performance. The latter was considered an indication of so-called "de-rating, " which might occur because of the modification to the original assembly design.

The code requirements at that time did not specifically address certain issues. None of the criteria listed below were specified to judge the performance of penetrations.

- Measurement of specific, allowable temperatures
- Pressures at which testing was to be conducted
- Allowable configurations of penetrating elements tested.

The last item above is critical; it is universally understood that in the event of a fire vented pipe installations will behave differently from unvented ones. Likewise, it has been demonstrated that tests of metallic-penetrating elements such as pipes or sleeves vary significantly depending on the length of sample (a direct consequence of thermal conductivity and exposed pipe surface area [11]).

Early publications describing test programs, including those at the (then) National Bureau of Standards in Washington, Ohio State University and the University of California, Berkeley, relied on ASTM E-119 testing methodology. Some of those tests compared how the use of plastic or metallic piping penetrating elements affected fire resistance. Other tests included methods to characterize and/or upgrade the performance of fire resistant assemblies when plastic pipe was installed [2],[3,12-20].

In addition to research being conducted in the U.S., in the 1970s the National Research Council of Canada published a series of reports. This research addressed the impact of furnace testing under positive pressure on fire endurance of through penetrations, including plastic pipe. In addition, this research also evaluated the impact of sleeves and the use of metallic pipe penetrants at wall and floor lines along with plastic DWV installations [18-20].

Arguments began to develop between the manufacturers and distributors of products being evaluated and the regulators and representatives of competing products, as well as labor unions. The arguments were primarily based on either underlying economic and competitive issues or how best to apply ASTM E-119 test methods and results. There were also discussions as to how tests were to be interpreted and what criteria regulators should reasonably apply to plastic piping installations [21-23].

In the late 1970s, in response to the growing controversy as to how best to test plastic pipe installations in fire-resistive construction, (as well as other classes of through penetration elements,) the ASTM E-5 committee began developing the E-814 Standard (Standard Test Method for Fire Tests of Through-Penetrations Fire Stops). This test method (also known as UL 1479 and UBC Std 7-5) was first approved as a consensus-based fire test method in 1983. It addressed the shortcomings of the ASTM E-119 method when testing plumbed and penetrated assemblies. It also clarified testing criteria: minimum sample sizes, instrumentation, and testing configurations. The E-814 test method also provided product developers, architects, and engineers with a uniform method by which to judge the properties of penetrations of all types. Testing could occur more readily and be more cost effective because the ASTM E-814 method did not require construction and testing of samples having minimum areas of 120 or 170 square feet for walls and floor/ceilings, respectively.

During the early 1980's various code change proposals were advanced to address safe use of plastic pipe in fire-resistive construction in each of the model codes. In addition, a joint effort under the umbrella of the Council of Building Officials - Board for the Coordination of the Model

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[c] This test method is also known as NFPA 251, UL 263, ANSI A2.1 and UBC 7-1

Codes (CABO-BCMC) produced a consensus document in 1986 entitled “Final Report on Protection Requirements for Vertical Penetrations” [24].

This report continued to recognize test results under the more complex ASTM E-119 test method, but interestingly also included caveats to address evaluations carried out using the ASTM E-814 method. Such code-mandated testing required (and still is in effect) that furnace exposures be conducted under positive pressures in the range of 0.01” of water (2.5 Pascal) to encourage through penetration failure by passage of hot gases that may have been inherent in tested designs.

Concurrently, in an effort to provide needed field installation information for fire-rated construction, the Plastic Pipe and Fittings Association developed the initial version of a fire safety manual for use by regulators, designers, and specifiers, which included design and test data. This document was first published in 1985, revised in1991 and again in1996 [25] as additional designs and test results for construction assemblies incorporating plastic pipe have become available. This publication has also been reviewed by representatives of the model code agencies for accuracy and was the subject of a CABO National Evaluation Report in 1992[26], and in 1995, the BCMC updated its guidelines—entitled “Protection of Penetrations and Joints in Building Wall, Floor and Roof Assemblies.” [27]—for protecting penetrations in construction.

The debut of the International Building Code (IBC) in 2000 includes provisions for plastic piping system applications in fire- resistive construction. It is eventually expected to replace the model codes promulgated by the three code bodies cited above. IBC Sections 711 (Penetrations) and 603 (Combustible Material in Type I and II Construction) address conditions and requirements for use of plastic piping materials in all building types, including those with non-combustible structural frames.

Historically, each of the [formerly regional] model code agencies cited above, has developed a model building code for adoption by local authorities having jurisdiction and by various state governments**.** These same agencies have also developed and distributed an affiliated plumbing code that addressed the performance of piping materials and systems. The plumbing codes generally did not address fire safety issues, with the underlying assumption being that the building codes address structural fire safety issues while subsidiary codes, such as the plumbing code, address specialized areas of product and system performance.

The exception has been the Uniform Plumbing Code [28]. This plumbing code, developed and promoted by the International Association of Plumbing and Mechanical Officials (IAPMO), had been distributed until the early 1990s by ICBO as part of its "Uniform" Code series. Before 1999 the UPC severely restricted the use of plastic pipe in fire- resistive buildings in many applications. Recently, the UPC permitted plastic piping installation only in buildings three stories high or less. In the 2000 code, however, the Uniform Plumbing Code was modified, allowing unlimited use of plastic pipe in constructions of all types.

During this same period the NFPA 101 " Life Safety Code" recognized the importance of protecting through penetrations in fire-resistive construction for piping and electrical systems (see Chapter 5 and Appendix "A" in the 1991 edition of the NFPA 101 document [29]. The Life Safety Code refers to the ASTM E-814 test method and includes a table summarizing performance requirements for through penetrations for both metallic and non-metallic piping types.

One critical factor in the code development over the last 20 years is the potential impact of fire spread due to positive pressures generated in structural fires. The BMCM was the first model code group to adopt the positive pressure requirement in its testing guidelines; other code groups followed suit. Unfortunately, the positive pressure testing issue has called into question early testing of pipe penetrations in furnaces, which did not necessarily apply positive pressures to tested specimens. Concern about the effects of positive pressure on the performance of floor/ceiling penetrations is warranted. Fires generate the maximum amount of positive pressures in the top one-third of affected rooms or compartments. Pressures below the top two-third of fire-affected rooms are negative in all but unusual cases and may actually encourages an inflow of cooling air at through penetrations like low on wall sink installations. [30].

The application of ASTM E-119 and E-814 to the testing of plastic pipe and penetrations provided model code developers with a firm understanding of the characteristics and properties of plastic pipe for use in structures. Thousands of fire endurance test reports based on assembly testing are available in books from accredited third party testing labs, as well as in design compendiums prepared by manufacturers and trade associations for use by architects, engineers, and other specifiers. Much of this data is also available in automated format on CD ROMs, which include construction detailing, relevant testing data, product performance, and related codes and standards information [31].

5.PLASTIC PIPE APPLICATIONS

The use of plastic pipe in a variety of building types and applications is reviewed below.

5.1 Plastic Pipe System Used in Fire-Resistive Construction.

Thermal expansion and contraction of plastic pipe in fire-resistive construction is a factor of concern in high-rise construction. The history and techniques on such installations is available in Robert C. Wilging's recent review [32]. Given that plastic piping materials are combustible, how can satisfactory performance be maintained if these products are incorporated in fire-resistive construction elements?

First, let us consider the characteristics of post-flashover fires, which may impact the integrity of through penetrations. Based on the data obtained from ASTM E-119 and E-814 testing, three general criteria can be used to determine acceptable performance:

- Increases in temperatures on unexposed faces of samples
- Maintenance of load bearing capabilities during and after fire exposure
- Development of openings in an assembly through which smoke and hot gases can travel.

In the case of the first and second set of criteria, the presence of additional combustible materials that might lead either to unwanted heat transfer or physical damage to a structural system where plastic pipe is installed must be evaluated. The tests to determine the impact of plastic piping systems were originally conducted in metal stud framed wall or wood framed analogs. In both cases the use of the plastic plumbing pipes did not reduce the wall's fire endurance <u>if</u> penetrations were sealed carefully and were not oversized. This suggests that the inclusion of plastic pipes did not create or lead to unusual heat transfer that could affect the integrity of structural systems under normal loading.

Fire endurance tests of cavity wall constructions including plastic pipe systems have determined when failure will occur when such installations are exposed to significant fire threats:

- horizontal through penetrations by plastic pipe tend to melt readily

- if the diameter of the pipe is 2” (50mm) or less, it is necessary to seal off at the unexposed face of the wall in question.

- if such horizontal piping is connected to vertical drain and vent sections, these can be expected to melt and then drop within a wall cavity before sufficient flaming occurs to transfer that flaming across the effected wall section.

Cavity temperatures, while above the melting point temperatures of the piping in the early stages of the fire exposure—say up to the first half hour—are still well below piping ignition temperatures of the pipe.[d] Likewise, because of its low thermal conductivity, creation of an ignition or fire spread threat due to high temperatures or heat conduction along through penetrating plastic pipes due to temperature increases will not occur. Figure 6 shows the remains of unburned plastic DWV pipe segment within a test wall cavity after a 30-minute ASTM E-119 fire exposure. The partially melted plastic in the wall cavity was not subjected to sufficient heat transfer to ignite or contribute significantly to fire impact on the test wall during the time of exposure.

A second important class of threat relates to the possible development of through openings when walls containing plastic pipe are exposed to fire. Such openings in walls and floor/ceilings will allow both unwanted fire spread to occur and, more importantly, will allow smoke and other products of combustion to spread from an initially effected area. Migration of such products of combustion away from fire-affected spaces can pose a serious life safety threat to both occupants in other portions of the affected structure and firefighters.

Both ASTM E-119 and in particular E-814 measure the development of through openings and reduction in penetration integrity through direct observation and required instrumentation. In addition, exposure of test assemblies under positive pressure testing conditions assures that if such openings do develop, released hot gases or other products of combustion will be detected.

The potential impact of combustion products from burning plastic pipe on life safety deserves comment. The amount of the piping product used is relatively small (in terms of total mass installed) when compared with other construction materials and the fuel load

[d] This behavior is similar to the properties of approved plastic glazing and ceiling inserts, which are designed to fall to floors of effected rooms before their ignition occurs

provided by room contents. In addition, the combustion products created when these products burn do not evolve early on in a fire because of how and where they are installed, nor are they more toxic than other products. Thus the behavior of properly installed plastic pipe in post flashover fires will not lead to unusual toxic hazard or threat [23, 33-36].

Directly related to the rigor of the furnace conditions prescribed by the E-119 time temperature curve (also prescribed for ASTM E-814 testing) is the thermal radiation levels in an E-119 test furnace. These levels are quite high, leading to extensive heat transfer throughout test samples. Because of temperature effects, radiation is the predominant mode of heat transfer during such testing, and overall test conditions and large sample sizes encourage thermal stress development in structural aspects of test assemblies as well as the penetrating elements themselves [37]. Thus, sample movement during testing, size of the sample, the restraint applied, and the nature of penetrating elements all affect the test results. Therefore, the following section discusses that different sizes and varyingly complex configurations of pipe installations in fire-resistive assemblies require different levels and types of through-penetration protection.

5.2 Fire Performance Guidelines

Although plastic piping systems may be based on different generic resins, all system discussed in this review are thermoplastic and all tend to behave similarly on exposure to fire conditions. Thus certain “rules of thumb” can be applied to evaluate the performance of plastic piping systems in various installations. Such installation may have differing wall depths, differing wall construction materials and techniques, differing pipe diameter, and the number of pipes installed at a given location[e]. To better understand the variables that affect plastic pipe installations and fire–resistive assemblies, an analysis of stresses that develop during fire exposure must be developed. Additionally, fire resistive assemblies that are fire endurance tested are rarely identical to assemblies built in the field because different design details create differences in the final configuration. Generalizations must be made as to how such assemblies will perform, whether or not they include plastic (or other plumbing systems) or wiring components.

Harmathy [38] presented a seminal analysis on the performance of fire-rated assemblies. This analysis included “rules” that are also applicable to fire assemblies including plastic pipe. Listed below are several of those rules, which have been paraphrased from the original version of the HUD Guidelines for the fire performance of archaic building materials [39].

- ***Rule #1:*** *Thicker assemblies (such as walls and floor ceilings) will, with all other things being equal, last longer than thinner walls of the same composition exposed to the same fire conditions.*

For example, when walls including plumbing are designed, they tend to be deeper than the same generic walls without plumbing. This is because when 3” (or greater) diameter piping is installed, wall depths greater than that standard 2”x4” framing must be used. If a generic wall has been tested as a 2” or 3” deep generic wall assembly (as with many designs found in the Gypsum Association Handbook [9]), then the deeper wall design with

[e] Because through penetrations of DWV piping present a more critical or vulnerable installation configuration, these will be the only ones considered. Membrane penetrations (which do not traverse and entire assembly directly) provide a less critical or potentially hazardous installation mode, as do small diameter penetrations and single pipe installations of sprinkler or supply piping under similar conditions.

the plumbing pipe can be expected to have longer fire endurance than the thinner analogs, providing openings for piping are carefully made and properly fire stopped. This is especially true for chase or multi-stud walls with thicknesses that are significantly greater than the common walls that separate rooms, (see Figure 9).

Figure 9

Chase wall design with PVC plumbing.

- **Rule #2:** Fire resistive assemblies containing hollow spaces tend to out perform similar analogs composed of the same materials without hollow spaces.

This rule reflects the greater insulating ability of air as compared to most common building materials, as well as the impact such voids have on thermal conductivity overall. For example, the thermal endurance of hollow clay tile assemblies or concrete slabs with void spaces as compared to solid analogs. Therefore, cavity walls with piping installed can be expected to perform better than the solid analogs with piping installed.

- **Rule #3:** Insulated assemblies can be expected to perform better than uninsulated ones.

In cavity walls the use of thermal insulation to reduce heat transfer in day-to-day use also leads to greater fire endurance. Thus, a stud wall of any type will be expected to perform better (with or without piping) if insulation is present. Such insulations do not have to be fire-rated materials but can simply be rated for thermal performance. These same insulations enhance fire performance and are cited in the calculated fire endurance methodologies found in the model codes for determining the performance of wood framed walls or for acoustical performance.

- **Rule #4:** Smaller openings in walls will lead to lesser diminution of fire endurance than larger openings.

As several of the fire endurance testing results presented here demonstrate [2,3,14-19], [30], it is possible to fire-stop a small diameter opening, i.e., a 1-1/2" diameter through penetration of DWV piping, by installing that pipe with minimal annular space using generic fire-stopping materials.[f] Conversely, multiple through penetrations, or those involving larger diameters of pipe, will require treatment with active through penetration fire-stopping systems, such as listed intumescent or thermal insulating materials, or cut-off devices.

Note, it is extremely rare for a fire resistive assembly to be built exactly as it is found in generic form as described in the tables of the model building codes. Such assemblies will

[f] These observations are consistent with those relating to the fire performance of small, individual electrical boxes installed with proper separation, as required by the building codes.

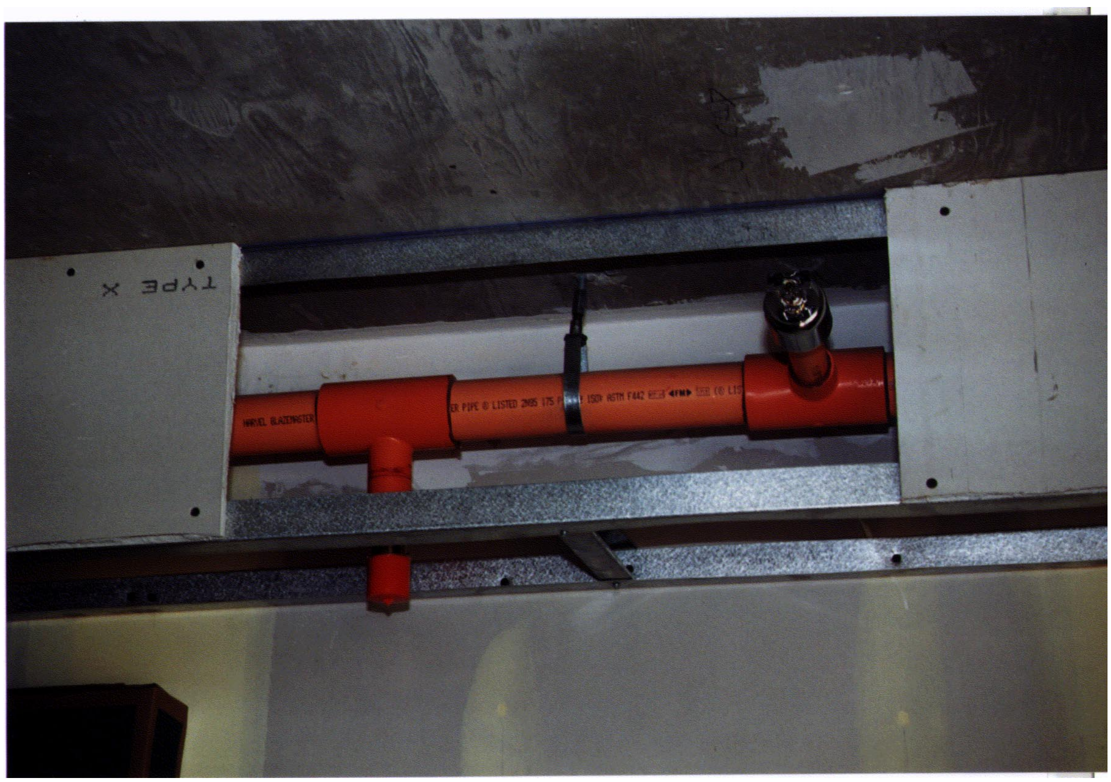
have piping present and/or electrical components and possibly insulation and other components for data transmission. It becomes the responsibility of the designer and regulator to understand how the inclusion of components such as piping elements will impact the performance of these walls if a serious fire occurs.

In summary, deeper walls, walls with additional layers of gypsum wallboard, and insulated walls will behave better in the event of a fire than walls without these properties. If these walls include piping components, tested fire-stopping approaches and technologies must be applied for all penetrations. Installations including larger diameter pipes or multiple pipe penetrations require more sophisticated fire-stopping approaches.

5.3 Sprinkler Systems Based on Plastic Piping Materials.

The use of sprinkler systems based on plastic piping materials has grown significantly over the past 15 years. A comprehensive review of initial development efforts was prepared by Wilging and published in 1988 [40]. Fire protection and cost/benefits provided through use of such systems has substantially impacted fire safety levels in single-family dwellings. Their installation has led to both increased life safety levels and a reduction in community expenditures to add fire stations in residential areas with extensive apartment complexes. Figure 10 is a photo of a typical plastic pipe sprinkler system.

Figure 10.



Typical sidewall installation plastic pipe sprinkler system.

Sprinkler systems that meet the requirements of UL 1887 (Fire test of Plastic Sprinkler Pipe for Flame and Smoke Characteristics) are usually fabricated from plastic CPVC and polyolefin resins and are to installed according to the following standards:

- NFPA 13: Standard for the Installation of Sprinkler Systems.
- NFPA 13R: Standard for the Installation of Sprinkler Systems in Residential Occupancies up to and Including Four Stories in Height.
- NFPA 13D: Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes.

As indicated in the previous section, these systems can also be used in air-handling spaces as regulated by the model mechanical codes and the NFPA 90A Standard. Piping materials and fittings can be used with both exposed piping (when fast response sprinkler heads are used) and with concealed piping for installations involving normal sprinkler heads. They cannot be used in dry piped systems and must not be installed with other types of plastic piping materials, such as those used for supply or DWV piping.

5.4 Firestopping Technology

The methods used to fire-stop pipe penetrations include both active systems--those that are activated in the presence of high temperature—and passive—those systems, which primarily rely on insulation as the fire-stop.

Active systems include intumescent materials or assemblies that activate and swell upon heating, thereby crushing softened pipes and filling openings with a hard char that is resistant to hose stream application. Other active systems include those which fill or cut-off openings when exposed to heat[41]. This latter class of fire-stopping devices can be seen at the bottom of the plumbing chase walls, as shown in figure 11. Hundreds of examples of these devices can be found in third party, fire-resistance rating directories.

Figure 11

Thermally activated firestopping devices in high rise building (see arrows).

Passive fire-stops include insulating materials or those that release components such as water vapor when exposed to certain temperatures. Kits that list and label components for specific configurations are available for plastic pipe installations [42]. Such kits may include wrap strips of materials, metal sleeves or collars, and intumescent or ablative or insulating solids.

Generic and non-listed materials (grout, sheet metal, thermal insulations) may be used successfully as fire-stopping components or materials, as well as those materials specifically listed and labeled for such uses. It is critical that any fire-stopping component be sufficiently similar to tested designs being used, and that generic materials be avoided for larger or multiple pipe openings, or for complex installations of longer duration. If these materials are used for such applications they must be first tested. From a liability perspective, it is suggested that listed and labeled materials be used for such applications.

5.5 Acceptance of Plastic Pipe Systems in Fire-Resistive Construction

A survey conducted in 1978 of high-rise buildings identified 108 high-rise or non-combustible buildings in 28 states that had been constructed using plastic piping for DWV systems (see Table 5.5.1) [43]. This survey was completed 8 years before the first regulatory efforts began to address use of plastic piping products. To the author's knowledge, all of these systems are still in use and none have suffered fire-related problems. No other systematic data appears to exist quantifying the use of plastic pipe in such complex structures, although they are routinely used in fire-rated buildings in many parts of the world today.

Table 5.1: High-rise buildings using plastic DWV by the early 1980's.

State	No. of Cities	No. of Buildings
Connecticut	4	4
Delaware	1	2
District of Columbia	1	6
Florida	4	4
Georgia	1	2
Illinois	7	7
Iowa	1	1
Kansas	1	1
Louisiana	1	1
Maryland	2	4
Massachusetts	1	1
Michigan	9	13
Missouri	1	1
Nebraska	2	2
New Jersey	2	3
New York	1	1
Ohio	3	7
Pennsylvania	12	15
South Carolina	1	1
Texas	6	26
Virginia	4	4
West Virginia	1	1
Wisconsin	1	1

Totals	67	108

In 1983 an Environmental Impact Report [44] was published regarding the expanded use of plastic pipe and the lack of regulations in the State of California governing its use. Based on the first draft of that study, Stanford Research Institute (SRI) [45] issued a report in 1989 and the State of California, Department of Housing and Community Development, published a final report in 1998 [23] endorsing the use of plastic pipe in fire-resistive construction. This endorsement was based on the research conducted by SRI and the State of California.

This author conducted a survey of eleven state, regional, and local jurisdictions. Historically, these jurisdictions have used various different combinations of model building and plumbing codes (see Table 5.5.2). More than half of the jurisdictions contacted placed no restrictions on the use of plastic pipe, regardless of building type, i.e., structural frame of non-combustible steel, concrete, or combustible wood frame. Other jurisdictions, however, banned the use of plastic pipe in wood-frame buildings. Many jurisdictions had problems enforcing relevant building code provisions to insure installation of appropriate firestopping detailing. Table 5.5.2 summarizes the results of that survey.

Table 5.2: Jurisdictions and model codes survey summary

Jurisdiction	CURRENT CODES IN USE	
	Plumbing	Building
State of California	1997 UPC[1]	1997 UBC
State of Michigan	1997 BOCA[2]	1997 BOCA
Southern Nevada	1997 UPC[1]	1997 UBC
State of Wash.	1997 UPC[3]	1997 UBC
Arlington Co., VA	2000 IPC	1997 BOCA
Bellevue, WA	1997 UPC[3,4]	1997 UBC
Seattle, WA	1997 UPC [3]	1997 UBC
Decatur, AL	1997 SPC	1997 SBC
Murphysboro, TN	1997 SPC[5]	1997 SBC
Cincinnati, OH	1997 BOCA	1997 BOCA

Notes:

[1] Code does not allow for unlimited use of plastic pipe
[2] Model code adopted locally may be more restrictive than the model code used
[3] Amended to allow unlimited use of plastic pipe
[4] Through July 2001
[5] Does not allow for use of plastic pipe in Types I & II buildings by amendment or local interpretation

With the availability of the newly combined 2000 International Plumbing Code and 2000 International Building Code, it will be interesting to see how and where the existing, model codes will be supplanted or used in conjunction with these new model codes.

The variety in the results listed above reflects the regional impact of political and economic interests, as well as technical factors on code adoption and enforcement of plumbing piping systems. As indicated earlier, certain economic interests have opposed using plastic pipe, leading to higher than necessary construction costs [46, 47]. The fact that such opposition is based not on technical grounds, but on economic ones is consistent with cost benefit data which show that installed costs of plastic piping based systems in fire resistive construction can reduce installed costs by as much as 40% [42,43]. For example, both the State of California and southern Nevada restrict the use of plastic pipe to structures no more than three-stories high, per the 1997 Uniform Plumbing Code [28]. With the advent of the ICC Codes, however, California will be adopting the 2000 International Building Code [49] along with the 2000 Uniform Plumbing Code[50] which allows unlimited use of plastic pipe. Given this change, it will be of interest to see what amendments may be added in state and regional jurisdictions to restrict plastic pipe use and on what "evidence" (sic) these amendments are made.

Many cities and states that have used the Uniform Plumbing Code as a basis for plastic pipe use have amended the code. For example, the state of Washington has used the Uniform Plumbing Code, but amended it to allow for unlimited use of plastic pipe and has been used in Seattle high-rise buildings for many years without incident. Whereas other cities and metropolitan areas, such as Las Vegas, Los Angeles and San Francisco, where economic interests oppose the use of plastic pipe in fire-resistive construction, have successfully lobbied to limit its use.

An arbitrary pattern of use of plastic pipe in types I and II non-combustible buildings exists related to local economic issues, despite the extensive testing that has been conducted, confirming its safe use in non-combustible buildings. It is unlikely these differences in regional and local adoption practices will be resolved in the near future unless some sort of federal building code series is imposed. This appears unlikely to happen soon, and the current “give and take” between local and regional economic interests will continue.

6. CONCLUSION

Arguments supporting the use of plastic pipe in fire-resistive construction are well founded and based on extensive testing, analysis, and review. The amount of testing and research conducted far exceeds that conducted with other piping materials. In addition, a positive field record supports the successful use of these products in all occupancies. Complementing this record is the tremendous of plastic pipe-based fire sprinkler systems on mitigating fires over the past 15 or 20 years. Clearly, if proper installation detailing is observed, plastic piping installations present no greater fire risk than other types of piping materials available on the market today.

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