

Plastic Pipe and Fire Safety

Prepared for the Plastic Pipe and Fittings
Association - PPFA

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1. INTRODUCTION

Plastic plumbing pipe, tube and conduit extruded from thermoplastic resins continue to be widely used in the US. ^a

Engineered applications - with these piping products installed as systems in fire resistive/fire rated constructions and assemblies - generally continue to show wide acceptance. Steady growth also continues in specialized areas such as hydronic systems, semi-fab applications including chemical supply and drainage systems, fire sprinkler systems and “green” applications. The latter include systems for thermal and electric solar applications, rainwater harvesting, geothermal energy applications, high efficiency hot water distribution, radiant heating, radon venting, central vacuum applications and gray water recovery.

Over the years the original emphases in the technical literature has been on basic properties of plastic piping systems. This emphasis has been augmented by applied engineering data related to expanded uses for plastic pipe in fire rated walls, floor/ceiling assemblies and fire penetrations in fire rated assemblies, sprinkler systems and process piping.

Contrasted with metal piping products used in buildings before the development of plastic piping systems, the documented fire performance of plastic pipe has been the subject of extensive basic research and more recently, engineering development in areas related to “Green Technologies” such as those listed above.

Regulatory reviews and discussions have occurred widely thru the years related to regulation of expanded uses of plastic pipe as newer applications became available. These have taken place 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), NFPA (National Fire Protection Association), ANSI (American National Standards Institute), the American Society for Testing Materials (ASTM), and IAPMO (International Association of Plumbing & Mechanical Officials) have generally added plastic piping documentation to their codes and standards.

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 as part of the HUD minimum standards used at that time.^{1,2} Subsequent peer reviewed analyses of the studies utilized existing fire resistance properties of buildings as starting points.³

These regulatory reviews frequently focused on building occupancy types to ensure that plastic piping product applications proposed for use in a given specific occupancy type was safe. A good example of this evolution can be found by comparing the California State Fire Marshal's review of plastic pipe and fire

^a The piping materials discussed here are manufactured from polyolefin, PVC, CPVC and ABS resins

safety published in 1980.⁴ That review concluded that use of plastic piping products in low-rise and residential or multi-family 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 proof of concept research to demonstrate acceptable levels of fire safety.

More recently - in 2015 – a newer Plastic pipe – EIR was prepared and submitted to the California Building Standards Commission by OSHPOD – the California Office of State Health Planning and Development Agency.^b This study included a review of health and safety issues including fire safety associated with specialized plastic pipe uses such as for chemical waste disposal in a range of hospital types.⁵

Today, U.S. model building codes do not restrict the use of plastic pipe by occupancy type or type of construction. Explicit in those provisions are caveats, such as those found in the ICC International Mechanical Code to ensure that appropriate attention is paid to uses in engineered buildings in general and that designs stress installation detailing in fire resistive buildings.

It is the objective of this review to update fire safety engineering issues associated with uses of plastic pipe and to summarize regulatory status of these materials which have evolved continuously since their introduction to the US in the 1950's and 60's.

2. PLASTIC PIPE AND FIRE ENDURANCE

Fire endurance is a measure of the length of time a given type of construction, assembly or element will remain serviceable in a given type of fire emergency. This broad statement applies to all types of buildings from single family dwellings to high rise or factory buildings.

In the vast majority of cases, plastic pipe is installed behind a barrier of some sort (a.k.a. a finish material) and rarely - if ever - does the pipe become involved as the first item ignited in a fire. The finish materials - walls or ceiling materials - form the "lining" or "boundary" of a room [aka a compartment] from a fire safety engineering perspective. The most common finish material used is gypsum wallboard a single layer of which will provide up to 20 minutes of protection to materials behind that layer of gypsum. Since plastic pipe is rarely installed in an exposed manner [except perhaps as a trap under a sink or in industrial applications] its use behind most typical finish materials ensures that it does not present a life safety hazard. This is because room occupants will have time to exit prior to loss of tenability in a room in a fire effected structure.

^b Study prepared to address Revisions for Plumbing Applications in OSHPD 1, 2, 3, and 4 Facilities, 2015.

In general, fires begin with ignition of a single item in a room and subsequent fire growth takes place when and if secondary ignition of nearby furnishings or light combustibles occurs. Plastic pipe or tubing installed behind gypsum wallboard or equivalent finish materials will resist any involvement with a growing fire for 15 minutes or more.⁶ In terms of life safety and available safe egress time [“ASET”]for occupants, conditions in such a fire effected room or compartment which threaten the gypsum finish materials occur only after human tenability limits are exceeded and before plastic pipe and tube materials become exposed to temperatures creating potentially untenable conditions.

This fire behavior and related effects on materials installed in wall cavities is consistent with repeated results of ASTM E-119 fire endurance testing^c which include hose stream exposures. The behavior of plastic pipe exposed in E-119 tests (Figs. 1-5) and post-fire evaluations of buildings that included plastic pipe in their construction demonstrate similar “real-world” behavior. Properly fire stopped plastic piping – as is required by the model building and mechanical codes, will either burn away and at wall lines or melt and drop in a wall cavity. PVC or CPVC materials will char in such situations as shown in Fig. 6 which shows remaining DWV piping condition after 30 minutes of E-119 test furnace exposure followed by the hose stream protocol.

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 review of fire incident databases, including those maintained and updated annually by the NFPA, they do not. These reviews demonstrate that in the U.S. during the last 40 to 50 years, no unique hazard or relationship has been identified or demonstrated that link the plastic pipe and tube class products to unusual fire ignition or fire spread.⁶⁻⁷

Considering combustion toxicity behavior is also important. Combustion toxicity data has been studied in attempts to identify potential links between uses of foreseeable amounts of properly installed plastic pipe in buildings and life safety threats. Results demonstrate that such piping does not create any unique hazard to room or building occupants when compared to other combustibles present. This conclusion is consistent with data published from the early 1980s through 1987^{8,9} which was 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 thoroughly reviewed information available at that time used by model building code agencies and state and Federal bodies regulating uses of plastic pipe and tube.

^c The most common fire endurance protocol used in the US, ASTM E-119, includes a hose stream exposure. This requires fire exposure of test specimens followed by application of a calibrated hose stream after half of the wall’s hourly rating. Such exposures consistently confirm that for unpenetrated or properly fire stopped walls with plastic pipe present, no de-rating of walls occurs.

A more complex question to be considered is how the presence of plastic pipe affects the life safety of occupants of a fire effected building other than where the fire initiates. To address this – as well as overall hazard-based performance of fire effected buildings – the impact of plastic pipe installations on the fire endurance of individual fire resistive assemblies needs to be considered. Assemblies considered must include all walls, floors, ceilings, shaft ways, and structural systems since these are at risk to be, affected when the building areas are exposed in a fully developed, post-flashover fire^d. Specific fire-resistive assembly designs are utilized in fire rated buildings to withstand post flashover fire conditions for specific periods of time. These tested designs are also utilized to prevent fire spread from fire affected areas to unaffected ones.

An example of fire-resistive construction frequently found in contemporary townhouse construction is the floor-ceiling assembly separating a ground level garage area from a first story living area. In such designs, a common construction feature specified is a two-hour fire rated concrete floor-ceiling assembly which may also act as an occupancy separation. These demise the more hazardous garage area from the living spaces above. In this case, the fire-rated slab and associated fire resistive construction features meet code requirements intended to prevent a fire that starts in a garage space from spreading rapidly into occupied adjacent dwelling spaces.

More complex fire resistive designs and constructions are found in high-rise buildings. In such buildings, fire endurance rated concrete slabs for floor/ceilings and walls and/or gypsum-based chase or shaft walls are commonly used to separate areas. In all cases, the design and detailing of these assemblies must include provisions for the safe distribution of utilities and other service assemblies traversing across sections, such as floor-to-floor, unit-to-unit, shaft-to-unit as well as the pressure driven effects (“stack effects”). The latter can drive products of combustion from fire effected areas if potential smoke effects are not considered in building designs.

The assemblies cited above, which routinely include plumbing, electrical, and HVAC elements must also include specific fire safety design features and possess fire endurance that the original floor/ceiling or wall design provided. Such designs may initially be considered generic. However, once utilities needed for a specific project are called out, the final design will become project specific and must include detailed specifications for features to resist fire spread.

^d These 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 specified levels 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.

Given the wide variety of construction features found in fire rated buildings, this review concentrates on walls or floor/ceiling assemblies, as these are most commonly associated with piping elements. These may be built as monolithic assemblies composed of slabs of concrete only or may include cavity wall designs or floor truss systems including plenum spaces for mechanical, electrical, or plumbing (MEP) elements.

Plenums occur frequently when metal trusses or wood studs and joists form a structural system. Plenum rated claddings/insulations for plastic pipe, tube or conduit used in plenums include both inorganic materials such as gypsum wallboard, mineral fiber or plaster. Variants of these structural systems, include single or multiple fire resistive membranes that are penetrated by piping. When only one membrane of such an assembly is penetrated (as can occur in a cavity wall or floor/ceiling assembly) these are referred to as *membrane penetrations*. Walls or floor/ceilings with piping running thru/across them and penetrating thru both faces are classified as having *through penetrations*.

Proper execution of fire endurance rated design features is important to maintain the integrity of all fire resistive wall and floor ceiling designs. These are found in the Gypsum Association Handbook or UL listed fire resistive designs ^{10,11}. Figures 7 and 8 show on site examples fire stopping construction and typical fire-resistive assembly configurations.

3. PLASTIC PIPE IN FIRE-RATED BUILDINGS

The plastic piping systems in most often cited as requiring effective fire stopping features to prevent fire spread are drain, waste and vent (DWV) piping. Rainwater drainage systems also present this design challenge. ***These pipes, used to transport waste and gases through a building, are obviously hollow and combustible. Without appropriate installation and mitigation features, such piping materials create potential failure sites in fire rated construction assemblies.*** As such, smoke, hot gases, and products of combustion could pass through these pipes if the fire resistance of MEP installations where they are included are not assured.

Plastic piping systems that are water-filled, pose less of a threat should a fire occur. These include plastic water supply piping and gray water and hydronic systems which transport hot and cold water from one part of building to another. Likewise, water-filled plastic sprinkler piping. 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 where common metal piping materials are subject to corrosion and failure. Like DWV applications however, these plastic pipe installations must include penetration fire stopping features wherever these are required. These piping applications are not vented and are generally smaller in diameter than DWV applications.

In general, smaller diameter pipe sizes reduce the risk of failure in the event of any fire and also reduce the relative size of the voids that may form when they melt in the absence of firestopping materials or devices. Figure 9 illustrates a suite of products with fire stopping technology applied including plastic DWV, supply and sprinkler piping.

Penetrations: As discussed above, the term "through penetration" refers to an opening that traverses a fire-resistive assembly. Such openings are installed for penetrations by piping, electrical, or other building services or possibly for joints (e.g., earthquake joints or construction joints) in concrete slab assemblies. Membrane penetrations comprise a sub-category of penetrations. Such penetrations differ from thru penetrations in that they refer to openings in fire resistive membranes which are part of the penetration needing to be fire stopped but which **do not** traverse the entire fire-resistive assembly. Rather, only a portion of the assembly is traversed. 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 penetrations maintain their integrity in the event of a fire, an appropriate thru penetration or membrane penetration firestop assembly or detailing is used. As such approved generic firestopping materials may be used as well as proprietary fire stopping systems. The latter are typically listed by third party listing organizations. 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).^e

Suitable materials used to firestop penetrations in a fire-resistive assembly will have been tested by, listed and labeled (referring to the test conducted) by an independent third-party testing laboratory. Installation parameters for a given product or system in a particular application can be found in listing documents or design guides. This information assists the AHJ in deciding whether to approve the materials used for a given installation. Conversely generic materials approved for such uses are typically referred to in the building, mechanical or fire code adopted in a community.

Sufficient testing of plastic pipe had taken place by the end of the 20th century to assure its safe use in buildings of all types. However, keeping up with contemporary fire safety engineering concepts, a new building classification - "Type IV" – Mass Timber Construction – was adopted by the 2021 International Building Code (IBC).

This adoption followed a trend, started in Europe and Asia, to utilize buildings as a method to store carbon in solid form. This new construction format typically involves use of laminated wood as entire

^e A recent technical update addressing inspection of fire stop installations, published by the Society of Fire Protection Engineers is available. Ref- SFPE "Extras," 11.2021 by Jeffrey Amato, PE, Jensen Hughes

components, such as, walls and floor/ceilings in buildings beyond seven stories in height, the previous limitation for combustible construction.

The 2021 IBC now allows for mass timber buildings up to 18 stories. To evaluate the suitability of plastic pipe installations in such mass timber construction, ASTM E-814 (penetration fire stop) fire endurance testing was conducted at a listed third-party testing agency. The sample tested was composed of 5-ply, 6-5/8" thick cross-laminated timber (CLT) panels covered with two layers of 5/8" type X gypsum wall board on the fire exposed side. In addition to fire endurance testing, hose stream exposures confirmed that the test sample demonstrated suitable fire endurance in excess of two hours. Penetrating elements included PVC DWV pipe installed with listed and labeled firestopping devices and caulk.¹²

Also, of interest with regard to mass timber construction are a series of peer reviewed papers from InterFlam Symposia (Fire and Materials. 2021; V.45). These deal with engineering applications of wall designs including those of mass timber construction fire testing.

4. PLASTIC PIPE: History and Fire Safety Provisions of the Codes

Regulations governing uses of plastic piping in fire resistive construction developed in tandem with development of needed data derived from evolving fire testing technology.

4.1 Historical:

Fire testing of assemblies with installed plastic piping systems began in the 1960's and 70's. In the U.S. at that time, HUD as well as three regional agencies promulgated model code requirements regulating fire resistive construction designs and performance. Consequently, the installations of plastic pipe in fire-resistive construction were based on testing according to the ASTM E-119 test standard, "Fire Tests of Building Construction and Materials". No formal performance criteria for penetration fire testing existed initially as discussed below.

Figure 12 illustrates an exemplar bldg. cross section including both vertical and horizontal penetrations. Note the superimposed furnace exposure geometries used for vertical or horizontal testing as needed for vertical or horizontal construction assemblies in this case equipped with penetrations.

To satisfy E-119 requirements, full sized fire resistive assemblies with plastic pipe installed have been subject to identical testing exposures dozens of times (See references 1-3, 6, 13-21, 23). Test Results for these plumbed assemblies were then compared to testing a given assembly tested *without* plastic pipe to determine the impact of the piping installations on assembly performance. If the plumbed wall showed inferior performance to the same wall design without plumbing, it was considered to have a de-rating

effect. To that point in time, no testing of cast iron based DWV piping had been run. Not surprisingly as an outcome, it was determined that ***all DWV installations*** - plastic and metal systems - needed to be fire stopped with tested materials and penetrations of membranes needed to be carefully cut and sized and penetrations at minimum be sealed with grout.

As noted above during this time period existing code requirements did not specifically address issues such as those listed in detail below and none of the criteria listed were used to judge the performance of penetrations:

- [Measurement of] Specific, allowable temperatures on penetrating elements
- Furnace testing conducted under positive pressure to simulate pressure profiles in rooms during fires
- Allowable venting configurations of penetrating elements tested

Possible effects of vented plastic pipe runs on fire performance were deemed critical. Consistent with this, it has become universally recognized that in the event of a serious fire impacting vented plastic pipe, vented pipe runs behave differently from unvented ones.^f 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).¹⁹⁻²¹

Early publications describing test programs, included those at the (then) National Bureau of Standards (now NIST), Ohio State University and the University of California, Berkeley. These described the ASTM E-119 methodologies used in their pipe testing programs which, in some cases, 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 resistive assemblies when plastic pipe was installed.^{2,3,13-21}

In addition to research conducted in the U.S., in the 1970's the National Research Council of Canada published a series of reports on piping fire issues. That research addressed the impact on fire endurance of furnace of testing of through penetrations under positive pressure including those fabricated with plastic pipe. In addition, the Canadian research evaluated the impact of sleeves and the use of metallic pipe penetrants at wall and floor lines along with plastic DWV installations.¹⁹⁻²¹

During this period, arguments between manufacturers and distributors of piping products being evaluated, regulators, labor unions and representatives of competing products. The arguments primarily referred to (a) underlying economic and competitive issues or (b) how best to apply ASTM E-119 test methods. These discussions also included how tests results were to be interpreted and what criteria regulators

^f Likewise, it has been demonstrated that tests of metallic-penetrating elements such as pipes or sleeves vary significantly depending on the length of sample (direct consequences of thermal conductivity and exposed pipe surface areas^f)

should reasonably apply to plastic piping installations²²⁻²³. The eventual results of these deliberations were code language describing requirements for safe installations of plastic pipe and tube.

By 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 Penetration Fire Stops). This test method, which is essentially identical to UL 1479, 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, penetrated assemblies in particular. It also clarified testing criteria including minimum test assembly sizes, instrumentation, and testing configurations.

E-814 (and UL 1479) testing was more efficient and provided cost-benefits 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. Acceptance of the E-814 test method provided product developers, architects, and engineers with uniform methods by which to judge the properties of penetrations of all types which continues. Today construction specifications and listings include literally thousands of approved fire stopping products.

During the early 1980's a range of 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 American Building Officials - Board for the Coordination of the Model Codes (CABO-BCMC) produced a consensus developed document in 1986 entitled "Final Report on Protection Requirements for Vertical Penetrations."²⁵

This report continued to recognize test results under a more complex interpretation of the ASTM E-119 test method. However, it also included caveats to address evaluations carried out using the ASTM E-814 method. This code-mandated testing required that furnace exposures for either standard test method be measured and conducted under positive pressures in the range of 0.01" of water (2.5 Pascal). Application of this requirement encouraged through penetration failure by forcing passage of hot gases where voids and weaknesses existed in fire stop designs. This approach enhanced overall fire safety of conforming penetration designs.

Fire safety related regulations governing the use of plastic pipe have evolved with both the technology of the piping materials themselves as well as with the associated installation technologies. The goal in both cases is to have piping installations and systems whose presence will not impact buildings and the fire safety of the occupancies negatively. More complex buildings require more complex fire safety solutions and features. Thus, fire safety installation requirements for plastic pipe in hazardous occupancies, schools, hospitals, and places of public assembly must be considered at all stages of construction.

Fire Risk: An important measure – which should always be considered in performing an analysis of fire risk with a product - is historical data is available that can be used to judge the product's past performance.

For fire risk studies, measures used need to consider how widely the product has been used and whether any systematic data exists by which such judgements can be drawn. In the case of plastic pipe, tube and conduit, an important question is whether **any** pattern or replicate series of events be identified that show a systematic risk of fire with these installations. While plastic pipe has been used for decades in low rise structures without identification of any meaningful shortcoming in terms of fire risk, important measures are those associated with building types and occupancies having higher risk found domestic single family and dwellings. To assess this, a review of the study described below allows us to **conclude that no systematic problem exists even with plastic pipe installations which predated the current regulations.**

The 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). This survey was completed 8 years before the first regulatory efforts began to address use of plastic piping products. To the author's knowledge, 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 it is routinely used in fire-rated buildings in many parts of the world today.

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

4.2 Development of Fire safety regulations: During this period the codes associated with residential uses evolved along with code administration and consolidation of code development processes.

This consolidation shifted code development from competing local and regional building code organizations [BOCA (Building Officials and Code Administrators), ICBO (Int'l Conf of Bldg Officials) and SBCCI (Standard Bldg Code Conf. Int'l)] to formation of the ICC (International Code Council) successor to the CABO process referred to earlier.

The ICC continues to administer construction related codes used currently throughout the US and the initial consolidation of the regional model codes, led to development of a comprehensive family of codes under the ICC. These defined fire performance properties of materials and features required to install plastic pipe were addressed uniformly.⁹

In the case of California and other states which utilized their own codes, the resulting codes adopted, included modifications of the model code versions. This took place as deemed appropriate at the state and sometimes local levels. This process continues today with the ICC Building, Plumbing, Mechanical and Residential codes containing language related to plastic pipe, tube and conduit used in construction. Regulations specifically applicable to installation of plastic pipe are found in sections of the International Building Code where fire resistive construction is included to address fire spread issues. In particular, the International Mechanical Code includes sections where use of plastic pipe with air handling plenums involved foreseeably affects fire and life safety. Comments on the various codes governing use of plastic pipe, tube and conduit follow.

During this period, in 1985 the Plastic Pipe and Fittings Association (Glen Ellen, Illinois) initiated development and publication of an installation manual series entitled "Plastic pipe and fire resistive construction." These were updated in 1991 and 1997 as new, tested designs became available.²⁶ Also during this periods data based systems of fire stopping products became available.³²

4.21 International Residential Code

The IRC, frequently referred to as the "One and Two Family Dwelling Code," refers to single and two family buildings but can also be applied to specific town house constructions up to three stories. The latter are described in IRC (scope) Section 101.2. The IRC also includes Appendix AG entitled "PLASTIC PIPING STANDARDS FOR VARIOUS APPLICATIONS." A companion Appendix Section, AG102 lists "Referenced Standards for approved uses of these products."

⁹ Also, during this period, the National Fire Protection Association (NFPA) regularly promulgated both a fire code which dealt with existing buildings and, more importantly the National Electrical Code (the "NEC") which includes regulations governing the use of plastic tube and conduit in electrical applications and which continues to be updated at regular intervals.

IRC Chapters 13 (GENERAL MECHANICAL SYSTEM REQUIREMENTS), 14 (HEATING AND COOLING EQUIPMENT AND APPLIANCES) and 15 (EXHAUST SYSTEMS) refer as needed to plastic pipe and tube used in these mechanical applications. Specific piping materials are addressed in Section 14.11.3.2. Likewise, the contents of the other sections of the IRC refer to fire safety thru specification of needed construction features as where plastic pipes traverse bored holes in structural members and the like.

4.22 International Building Code – The IBC includes comprehensive requirements intended to maintain the fire resistive integrity of building features. These include walls, floor-ceiling, and roof-ceiling assemblies as well as features such as shaft walls. In addition to assembly fire resistance requirements, IBC includes Section 714 explicitly addresses penetrations of FR assemblies including those for plastic pipe and tube in a detailed manner. More generally, IBC Chapter 7 “Fire and Smoke Protection Features” comprehensively addresses and specifies necessary features of FR assembly designs.

4.23 International Mechanical Code – Most references to plastic pipe and tube in the 2021 edition of the IMC remained unchanged from previous editions. However, IMC Section 602 - *which addresses plenum construction* - was modified significantly with respect to plastic pipe and tube. It also included revised specific references to uses of plastic pipe, tube, and conduit in plenum spaces.

Plenum constructions are important because, in addition to their air handling functions, they are frequently used to facilitate cost effective MEP system installation. At the same time, however - and overriding cost concerns - compliant installation of all MEP elements are crucial to maintaining life safety and tenability in buildings which include air handling plenum constructions. This is because fire performance of materials of construction and functional designs of plenums used for air handling strongly controls fire, smoke and hot gas development and movement between building areas when fires occur.

For this reason, materials and products used to construct fire rated plenums including MEP components must be demonstrated to be resistant to ignition, flamespread and smoke development.

For many years the ASTM E-84 flamespread test, which is conducted in a test furnace called the Steiner Tunnel, has been relied upon to provide data describing flamespread and smoke development properties of a wide range of building materials and products. However, as fire rated construction requirements have become more complex, the lack of flexibility for mounting products and materials for E-84 testing other than those which are used as flat sheets as specified in E-84 for product testing, has complicated matters for architects, engineers, code officials and product manufacturers. Such products include in addition to plastic piping, duct materials, insulations, pneumatic tubing, optical fiber raceway and components.

In response to the need for product-oriented test protocols which utilize the tunnel furnace and provide product specific mounting methods and measurement schemes different from E-84, a series of product-oriented test methods for tunnel testing have been developed by ASTM, UL and the NFPA.

In response to the need to have these product-oriented test methods in the IMC, Section 602.2 “Construction” (i.e., constructions relating to plenums)” and 602.2.1, “Materials Within Plenums” were developed.

Specifically, Section 602.2.1 required that classical materials utilized as flat sheets – such as gypsum wallboard or wood-based paneling such as OSB - installed in plenums be either non-combustible or meet the 25-50 flamespread – smoke development criteria as applied to E-84 test results.

However, many items not available as flat sheets are installed in plenums but cannot be tested readily based on E-84 mounting requirements developed in the days of the 1940’s Coconut Grove Fire. These include electrical wiring and mechanical components, sprinkler pipe, pneumatic tubing, optical fiber raceways and discrete items such as signaling or wi-fi components, smoke detectors and the like.

Today these materials constitute a class of items which, under language included in Section 602.2.1 are considered using other test methods as alternates to ASTM E-84 *but* which reliably measure flame travel and smoke obscuration under test conditions consistent with those required in ASTM E-84.

As such for plastic pipe and tubing, UL 2846 (UL Standard for Safety Fire Test of Plastic Water Distribution Plumbing Pipe for Visible Flame and Smoke Characteristics) was added as an approved alternate to E-84 in IBC Section 602. The specific language in IMC section 602.2.1.7 referring to plastic pipe uses in plenums, adopted in 2018 is as follows:

602.2.1.7 Plastic plumbing piping and tubing. Plastic piping and tubing used in plumbing systems shall be listed and labeled as having a flame spread index not greater than 25 and a smoke-developed index not greater than 50 when tested in accordance with ASTM E84 or UL 723.

Exception: Plastic water distribution piping and tubing listed and labeled in accordance with UL 2846 as having a peak optical density not greater than 0.50, an average optical density not greater than 0.15, and a flame spread distance not greater than 5 feet (1524 mm) and installed in accordance with its listing.

In this way, UL 2846 joins other standards for evaluating mechanical, electrical, or plumbing items used in plenum construction such as UL 1887 for plastic sprinkler pipe, UL 1820 for optical fiber raceways and NFPA 262 for plenum rated wire and cable.

Because of concerns regarding the hollow nature of *plastic drain waste and vent piping*, *this class of piping is explicitly excluded from testing under UL 2846*. In addition, when used in plenums, assemblies incorporating plastic DWV piping must be protected with plenum rated insulation.

The development and application of UL 2846 and its associated requirements are important because plenum requirements are the most stringent materials-based fire performance requirements in the codes. They also establish norms for the most fire-resistant products found in construction today from a life safety perspective.

The availability of the UL-2846 Standard to qualify materials such as polyolefin (PEX) tubing, used in hydronic heating, cooling and other “green” applications is an important application of this contemporary testing technology.

4.24 The NFPA 90a standard

The development and acceptance of UL 2846 has also made available compliant plastic pipe and tube for plenum uses where they specify compliance with the NFPA 90a (Standard for the Installation of Air-Conditioning and Ventilating Systems). The acceptance language in NFPA 90a also emphasizes that installations including plastic pipe and tube materials must meet NFPA’s UL – 2846 criteria and cannot be tested with water included in the pipe during testing.

4.25 IAPMO Mechanical Code – the Uniform Mechanical Code

An additional code writing organization continues to promulgate the Uniform Mechanical Code (UMC). This is the International Association of Plumbing and Mechanical Officials. This code remains an outlier to the ICC process but remains in use in several western states. With amendments it forms the basis for the California Mechanical Code. The UMC is considering adoption of UL-2846 currently. It appears to the author that opposition to its adoption is based on political and marketing pressures rather than sound technical arguments.²²

5. PLASTIC PIPE APPLICATIONS

Uses of plastic pipe in a variety of building types and applications are reviewed here.

5.1 Plastic Pipe Systems 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. A history and description of techniques for such installations is available in Robert C. Wilging's review ³³

Given that plastic piping materials are combustible, satisfactory fire resistance must be maintained if these products are incorporated in fire-resistive construction elements and building overall. This section considers characteristics of post-flashover fires, which impact the integrity of plastic pipe installations including those in membrane and through penetration formats.

Consistent with data obtained from ASTM E-119 and E-814 testing, the following three criteria determine acceptable performance for walls and floor ceilings which include plastic pipe and tube.:

- Increases in temperatures on unexposed [back face] test assembly surface
- Maintenance of load bearing capabilities of assemblies during and after fire and hose stream exposures
- Development of openings in an assembly sufficient to allow flame, smoke, and hot gases to escape from the back face of tested assemblies

The first and second criteria above address thermal and structural performance. In all three cases however, it is the presence of materials that might lead either to unwanted heat transfer or physical damage to a structural system where plastic pipe is installed that are evaluated.

Tests to determine the impact of plastic piping systems have been conducted on both metal stud framed and wood framed assemblies. In both cases the use of the plastic plumbing pipes did not reduce the wall's fire endurance if penetrations were treated with listed and labeled products. When these criteria were met, plastic piping systems did not create or lead to unusual heat transfer that could affect the integrity of structural systems under load. Fire endurance tests of cavity wall constructions including plastic pipe systems were used to determine failure mechanisms operating when installations were exposed to lab testing simulating conservative, fully developed fire conditions. These were identified as follows:

- horizontal, unprotected through penetrations by plastic pipe
- small diameter pipe - 2" (50mm) or less – without annular spaces carefully sealed
- horizontal piping with firestopping connected to vertical drain and vent sections. If not protected properly these will melt and drop within a wall cavity and if sufficient flaming occurs to that flaming exits the unexposed face of the wall.

Contributing to these behaviors - cavity temperatures while above the melting point temperatures of the piping in the early stages of the fire exposure - up to the first half hour - are still well below ignition temperatures of the pipe.^h Likewise, because of low thermal conductivity, ignition or fire spread threats

^h 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

due to heat conduction along through penetrating plastic pipes due to temperature increases will not occur.

Figure 6 shows the remains of an 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. These will allow both unwanted fire spread to occur and importantly, will allow smoke and other products of combustion to spread from the initially effected area. Migration of 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 if fire resistive elements fail.

Both ASTM E-119 and particularly E-814 measure the development of through openings and reduction in penetration integrity. This is accomplished using both direct observation and required instrumentation for temperature rises. In addition, exposure of test assemblies under positive pressure testing conditions assures that if such openings do develop during a test exposure, hot gases or other products of combustion will be detected.

The potential impact of combustion products from burning plastic pipe on life safety is low. This is a result of the amount of the piping product used is relatively small (in terms of total mass installed) when compared with other room furnishings and construction materials potentially involved. Combustion products created when piping products burn do not evolve early on in a fire because of how and where they are installed. Likewise, they are no more toxic than other products commonly found in buildings. Thus, the behavior of properly installed plastic pipe in post flashover fires will not lead to unusual toxic hazards or threats.^{9,34-35}

Directly related to the rigor of the test furnace conditions prescribed by the E-119 time temperature curve (also prescribed for ASTM E-814 testing) are thermal radiation levels in an E-119 test furnace. These levels are 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.³⁶ Thus, strain – measured responses to stresses imposed - reflected in sample movement during testing, size and scale of the samples, restraint applied, and the nature of penetrating elements all affect test results.

5.2 Fire Performance Guidelines

Certain "rules of thumb" can be applied to evaluate the foreseeable performance of plastic piping as used in various systems and installations. Installations differ in terms of wall depths, construction materials and techniques, pipe diameters and number of pipes installed at a given location must be considered.ⁱ

Additionally, fire resistive assemblies that are tested for fire endurance are rarely identical to assemblies built in the field. This is because different design requirements and details create differences in final configurations. However, generalizations can be made as to how such assemblies will perform, whether or not they include plastic pipe (or other plumbing systems) or wiring components.

"Rules of thumb" - Harmathy developed a valuable suite of analyses of factors effecting the performance of fire-rated assemblies generally. His analysis included "rules" governing post flashover fire resistive assembly performance that are readily applicable to assemblies which include plastic pipe, tube and conduits. The list below cites some of those "rules", paraphrased here from the original version published in the **HUD Guidelines for the Fire Performance of Archaic Building Materials**.³⁸

- **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.*

Comment: When walls including plumbing are designed, they tend to be deeper than the same generic wall designs 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,¹⁰ then the deeper wall design with the plumbing pipe can be expected to have equivalent or longer fire endurance than the thinner analogs, providing openings for piping are carefully made and properly fire stopped with listed or labeled materials and techniques 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 14).

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

Comment: This rule reflects (a) the greater insulating ability of air as compared to most common building materials, and (b) the impact such voids have on thermal conductivity overall. For example, the thermal

ⁱ 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.

endurance of hollow clay tile assemblies or concrete slabs with void spaces are greater compared to solid analogs made with the same depth and materials. 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.

Comment: In cavity walls the use of thermal insulation to reduce heat transfer in day-to-day use also leads them to have greater fire endurance than un-insulated analogs. 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. (See Figure 15.)

- **Rule #4:** Smaller openings in walls will show less of a reduction in fire endurance than identical assemblies with larger openings.

Comment: As fire endurance test 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^j. 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 mechanical fire stopping devices.

As noted earlier, 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 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. (See fig 16)

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. A comprehensive review of initial development efforts which began in the 1960's and led to eventual acceptance with NFPA

^j 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.

sprinkler standards was prepared by Wilging and published in 1988.³⁹ The PPI initiative in 1978 marked the initial formal adoption of a program to develop NFPA compliant systems. The article, published in the BOCA Journal, also included an editor's note pointing out that suitability of plastic pipe for sprinkler applications in the NFPA standards was *not* to be interpreted by the local AHJ, but rather the listing for the pipe and the sprinkler service requirements.

Interestingly while CPVC piped sprinklers and later polyolefin-based systems have been accepted for UL 1626 applications, until recently no non-metallic sprinkler heads have been available until recently. Plastic heads are now available for certain approved systems which eliminate the complications posed by lead and zinc associated with metal alloy-based head technology. The new head types are manufactured by injection molding of Polyphenylene Sulfide, a high-temperature capable engineering polymer used in the aerospace and automotive industries for some years.^k

Fire protection and cost/benefits provided through use of these systems have substantially impacted fire safety levels in single and multi family dwellings in which they are installed. As their availability increased and their use in multifamily homes expanded, local fire protection costs were also provided with cost-benefits. Their installation has led to both enhanced life safety and reduction in community expenditures to add fire stations in residential areas with extensive apartment complexes.

Beginning with the 2015 International Building Code, installing sprinklers at all residential buildings was added as a code requirement. A comprehensive review of these systems prepared by the National Fire Sprinkler Association can be found at <http://nfsa.org> in their "Fire Sprinkler Guide – IBC."

The addition of requiring these systems is not without controversy since the costs of installing sprinkler systems in all new homes had to be passed through the home builder to the home purchaser. For this reason, the requirement for sprinkler installations in all new homes became a focus of debate at state and local level code adoption proceedings. An important cost benefit takes place in the installation of these systems in manufactured homes where the economics of factory operations take place.

Piping for systems that meet the requirements of UL 1887 (Fire test of Plastic Sprinkler Pipe for Flame and Smoke Characteristics) are most frequently manufactured from CPVC and/or polyolefin resins. The installation requirements must be meet one of 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.

^kThe subject of plastic piped sprinkler systems was recently reviewed (12/2021) as part of an SFPE Webinar by James Silva, PE of Johnson Controls.

- 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 standard response sprinkler heads. These systems cannot be used in dry piped systems and must not be installed with other types of plastic piping materials, such as those used for water supply or DWV piping.¹

5.4 Firestopping Technology

The methods used to fire-stop pipe penetrations include both active systems--those activated in the presence of high temperatures -and passive systems which primarily rely on insulation to prevent fire spread.

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.⁴⁰ Over a thousand examples of these devices and materials can be found in third party rating directories. Passive firestops 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 widely available for plastic pipe installations⁴². 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, generic 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. A consistent example of the latter is fire stopping used for NRC regulated utility plants.

For any of the generic materials used for fire stopping applications, successful tests for fire endurance must be available. Also, from a liability perspective, it is strongly suggested that listed and labeled materials be used for such applications.

¹ Information on the new non-metallic head technology is available from James Siva, PE of Johnson Controls or thru SFPE.

5.5 Acceptance of Plastic Pipe Systems in Fire-Resistive Construction

In the 1960s and through the 1970s there was significant resistance to so use of plastic pipe in buildings whose “construction type” was referred to as “noncombustible.” This created confusion in that while the “construction type” referenced only the structural system of the building, regulators sometimes also classified piping systems as part of the structural system.

As the technology for ensuring that plastic pipe installations did not adversely affect fire resistance of building structural systems evolved however, model code language was clarified to address this issue. While there are still local jurisdictions where height limitations for use of plastic pipe exist or have been inserted or substituted in model code language as part of local adoptions, such restrictions are not based on fire risk or hazard issues or other sound technical arguments. Rather they are based on objections based on marketing/economic issues and special interests.

6. CONCLUSION

Use of plastic pipe, tube and conduit in fire-resistive construction is wide-spread in all construction types and occupancies. Those uses are based on extensive testing, analysis, and review. The volume of testing and research conducted consistent with the reference list available 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 positive influence of plastic pipe-based fire sprinkler systems on mitigating fires over the past 15 or 20 years. Clearly, if tested designs are used and proper installation detailing takes place, plastic piping installations present no greater fire risk than other types of piping materials available on the market today.

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