(BSS-68)

NBSIR 74-531

Review of Performance Characteristics, Standards and Regulatory Restrictions Relating to the Use of Thermoplastic Piping in Residential Plumbing

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Institute for Applied Technology
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Interim Report for Period
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

CONTENTS

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by

R. S. Wyly, W. J. Parker, D. E. Rorrer,
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ABSTRACT

The paper is a review of existing information on the physical characteristics of thermoplastic piping that are of particular interest in considering its potential for use in residential, above-ground plumbing. The presentation is oriented to considerations of adequacy of functional performance of plumbing systems from the user's/owner's viewpoint, in contrast with the typical product-specification oriented format reflected in current standards.

Not only are the physical characteristics emphasized that relate most directly to the determination of functional performance of installed systems, but the importance of design and installation detail in this context is discussed.

In conclusion, this review indicated the need for better use of existing knowledge as well as for some research and test development work particularly in the areas of thermal properties, response to building fires, and resistance to water hammer.

Key Words: Fire performance of piping; functional performance of piping; performance characteristics for piping; thermal/structural performance of piping; thermoplastic piping in plumbing.

1. INTRODUCTION

1.1 Background

Most of the present standards for piping materials describe the physical properties of specific materials, and are utilized particularly for quality control in the manufacturing process. Generally such product standards provide the kind of requirements and tests needed by specifiers and purchasers to determine whether or not a piece of pipe or a pipe fitting does in fact comply with the standard specification that the manufacturer claims it does. However, these product standards do not define, under conditions of use, direct measures of the probable functional, health/safety, and durability performance of the assemblies of pipes and fittings in relation to the materials characteristics. This lack of end-use performance criteria is a serious shortcoming in expeditious determination of acceptance for innovative materials through application of the performance concept.

The widespread utilization of performance-type standards would not eliminate the necessity for the product standards. The use of such specification-type standards must continue as a means for assuring uniform quality and for identification of the product. Also in the perfection of performance tests the traditional, quality-control type of tests could be useful in determining some of the general properties of the new materials. In establishing meaningful performance tests it might also be necessary to conduct additional, special tests to study the properties of the systems that are involved.

The traditional metal piping used in the construction of plumbing systems may no longer provide the most economical and satisfactory long-range solution for all residential plumbing systems. Reliable skilled labor for assembling plumbing systems in the field is becoming more difficult to obtain in the numbers needed to meet the demand, consequently there is a trend to develop larger components and factory-assembled systems to speed on-site construction. The plumbing industry is moving in the direction of utilizing alternative materials not only for economic reasons, but also in order to conserve resources. Among the considerations involved in this trend are those relating to alternatives for the convenience of manufacture and assembly.

Thermoplastic piping has been demonstrated to be an economic alternative to metal piping in terms of first cost and convenience of assembly. However, several technical questions relating to service performance need to be answered. Evaluation programs are needed to determine whether the new materials will be satisfactory throughout the planned life expectancy of the system and of the components in which they are used. Because piping systems constructed of traditional materials have been generally acceptable, there is a strong tendency to evaluate new materials by a comparison of some of the physical properties of the new materials with selected favorable physical properties of the traditional materials, and to design piping systems around these same selected properties of traditional materials. Such an approach restricts the scope of the evaluation and may misdirect the point of concern to the extent that potential exists for the exclusion of innovative materials and methods; whereas the real concern is whether or not the plumbing system, as installed, performs satisfactorily and whether or not it provides the durability appropriate to the system and its intended functions.

Performance requirements and performance criteria for satisfactory systems need to be identified as the first level of concern. Then evaluative techniques may be developed to determine the adequacy of the performance of the new materials under typical end-use conditions as parts of a plumbing system.

During the past several decades, non-metallic materials have progressively replaced metallic materials in many applications. Thermoplastic materials are being used in building construction for water service and water distribution piping; for drain, waste and vent piping; for electrical conduit, and for gas service. Table 1 lists a number of such materials but only four have been used generally for residential plumbing: (1) Acrylonitrile-butadiene-styrene (ABS) and (2) Poly(vinyl chloride) (PVC), both used where plastics are approved for drain, waste, and vent systems, but PVC to a lesser extent then ABS, (3) Chlorinated poly(vinyl chloride) (CPVC) recently introduced for use in hot and cold water distribution systems, and (4) Polyethylene (PE) for underground and water service piping.

Piping[1/] with thermoplastic materials exhibits special characteristics different from piping constructed of the traditional metallic materials. Some of these characteristics yield advantages, but others may lead to difficulties under some conditions.

1/ A number of terms have been defined in Section 7.

Table 1. Tabulation of Plastic Materials Used in the Manufacture of Plastic Pipe and/or Fittings for Various Applications.

- Acetal (AP)
- Acrylonitrile-butadiene-styrene (ABS)
- Cellulose-acetate-butyrate (CAB)
- Chlorinated Polyether
- Chlorinated poly(vinyl chloride) (CPVC)
- Glass Fiber Reinforced Epoxy
- Glass Fiber Reinforced Polyester
- Polyamide [nylon] (PA)
- Polybutylene (PB)
- Polychlorotrifluoroethylene (PCTFE)
- Polyethylene (PE)
- Polyethylene, Biaxially Oriented (PEO)
- Poly(methyl methacrylate) (PMMA)
- Polyolefin (PO)
- Polyoxymethylene [polyacetal] (POM)
- Polyphenylene Oxide (POP)
- Polypropylene (PP)
- Polystyrene (PS)
- Polytetrafluoroethylene (PTFE)
- Poly(vinyl chloride) (PVC)
- Poly(vinylidene chloride) [saran] (PVDC)
- Poly(vinylidene fluoride) (PVDF)
- Polyurethane Elastomer (PUR)
- Poly(styrene acrylonitrile) (SAN)
- Reinforced Plastic Mortar Pipe (RPMP)
- Styrene Rubber (SR)

Any thermoplastic material, by definition, can be reshaped by raising its temperature above some characteristic value, a value which is a much lower temperature than is needed to soften any of the traditional metallic materials. For this reason, the operating temperature (ambient and internal) is of critical concern for structural stability. Within the piping structure, when thermoplastic materials are used, there is a greater movement under hydraulic and thermal loading and in addition there may be measurable creep effects. Although plastic piping is highly resistant to corrosion of types that frequently attack metals, questions have been raised as to the susceptibility of thermoplastics to environmental stress cracking under service conditions. Because the thermoplastics being used for plumbing are more or less combustible, the presence of toxic combustion products in building fires and the possible effect on fire spread must be considered. The effects of some ordinary drain-cleaning fluids and household chemicals and solvents may need to be further evaluated. In general, thermoplastic piping may be less resistant than metal to abrasive and scraping agents which means that the selection of devices used for internal cleaning needs to be considered in this context. An attractive feature of thermoplastic piping is its lightness which reduces structural loads on a building and makes for convenient fabrication and erection. However, care must be given to supporting the piping and to providing clearances since compared to metal pipe, the greater movements under dynamic, hydraulic and thermal loads can create acoustical problems from pipe impact or from localized contact with the building structure. Concentrated drain-cleaning agents like powdered sodium hydroxide with aluminum particles may under some conditions cause a localized exothermic reaction that can overheat the material.

Care in supporting plastic pipe is also required because of the tendency of the pipe to deflect with increased temperature such as may occur in domestic hot water systems. Some problems may occur with respect to dimensional stability under intermittent thermal loading over a long period of time, if an inappropriate material or an inappropriate application is selected. If plastic pipe is not adequately supported and adequate provisions are not made to accomodate the expansion, contraction and long-term dimensional changes that may occur in response to thermal loading, then functional difficulties may be encountered.

A considerable technology has evolved since the first poly(vinyl chloride) (PVC) compounds were developed by German technologists in the 1930's and since the advent of the thermoplastic pipe industry in the United States in 1948. There has been a gradual improvement in the impact strength, durability, and material consistency through quality control and product standards. Improvements in these areas and in design specifications for particular applications have led to an increasing acceptance by designers, contractors, and building code officials.

The instances of faulty application of plastics may be related to one or more of several main factors:

(1) Plastics, a generic term, identifies broadly a large number of materials whose composition or characteristics were neither well known nor understood by the plumbing and building industry.

(2) In the environment of the plumbing system the temperature range and its effect were not well known.

(3) The system characteristics of expansion and contraction, deflection and change in slope and the consequential requirements for jointing and support were not sufficiently well known.

(4) The degree of fire hazard and the accompanying toxic gas hazard were little known.

(5) The matching of requirements to material properties could not be done adequately.

Some examples of complaints reported by the users were [1][2/]: annoying acoustical problems from hydraulic flow and uncontrolled movement; loss of slope, bursting or the development of leaks from the effects of hot water; or disintegration as a result of normal exposure to household chemicals. Such difficulties could actually reflect inappropriate design and installation, and misuse by an uninformed community, resulting from one or more of the factors listed above. To exclude thermoplastic piping from plumbing use because of potential fire hazards would be unreasonable without a consideration of the relative design situation. For example, much of the thermoplastic piping is so located in a room or so located in a wall that it would rarely be involved in a fire in the early stages of its development. Also, design and installation techniques can be used to reduce the potential fire spread and transmission of smoke and toxic gas into critical areas.

1.2 Objectives and Scope

As a part of the HUD long-range research program for improving building standards, a definitive broad task was sponsored by HUD for NBS to develop performance criteria for piping materials, subassemblies, and systems for residential plumbing. Because of the pressing nature of prevailing issues, the scope of this study was limited to the evaluation of non-metallic piping materials, subassemblies and systems for residential plumbing. The items of particular concern were: thin-wall PVC drain-waste-vent systems, tube-size CPVC water-distribution piping, and the single-stack drainage system. The findings on the latter item, an issue not related to the properties of the materials, are reported separately [2].

The principal objectives in this study were as follows:

1. To describe the current status of experience with thermoplastic piping, particularly for residential, above-ground plumbing.

2. To present the rationale for the application of performance concepts in standards for piping.

2/ Numbers in brackets refer to sequential listing of references in Section 6.

3. To identify some of the technological parameters that must be addressed in the formulation of performance criteria for piping materials. The scope of the report is limited to the consideration of some thermoplastic materials, and takes into account a number of factors thought to be significant in any application of thermoplastic piping. Included are certain use limitations, some essential criteria that are related to design and installation, and current recommendations concerning maintenance and use of plumbing systems.

This report identifies existing model codes and voluntary standards, reports data gathered by contact with manufacturers and laboratories, includes a survey of technical literature, and gives information obtained by NBS from on-site inspection at the King County Operation BREAKTHROUGH Prototype Site. Specific recommendations are made concerning parameters that need to be considered in research programs intended to produce criteria for the design and evaluation of piping materials as used and installed in plumbing systems. This report does not present data obtained from experimentation in all recent test programs. Such data have been or will be reported separately.

1.3 Codes and Standards Relating to Thermoplastic Piping

Standards provide the basis for mass production and interchangeability of components of plumbing systems. Codes utilize standards as the basis for identification of minimum acceptable level of both the quality and performance of the plumbing components.

As a legal instrument adopted by a governmental body (generally a city, county, or state), a code regulates the practice, design, and installation of plumbing, predicated on the need for the protection of public health and safety.

A model code is an aggregation of recommendations concerning the practice, design, and installation of plumbing, presented in generally accepted format to facilitate legal adoption by regulatory authorities. The principal model codes and sponsors in the United States today are:

1. The Uniform Plumbing Code (UPC) of the International Association of Plumbing and Mechanical Officials (IAPMO).

2. The BOCA Basic Plumbing Code (BPC) of the Building Officials and Code Administrators International, Incorporated (BOCA).

3. The Southern Standard Plumbing Code (SSPC) of the Southern Building Code Congress (SBCC).

4. National Standard Plumbing Code (NSPC) of the National Association of Plumbing-Heating-Cooling Contractors (NAPHCC).

The NAPHCC model code now exists as the latest evolvement from the American Standard National Code, ASA A40.8---1955. This model code was widely adopted and used until recently. When extensive effort to produce an updated document failed to produce a consensus as determined by ANSI, A40.8---1955 was withdrawn by ANSI in 1972. A technically similar, updated document is considered here to be the fourth model code and the latest revision of this document, cosponsored by The American Society of Plumbing Engineers (ASPE) and NAPHCC, is now accepted by the Department of Housing and Urban Development as a model code for program purposes under the Workable Programs for Community Improvement.

Variations in codes develop at a local level because of abnormal prevailing environmental conditions, such as seismic, hurricane, flooding, or freezing; the durability of materials in different soils and water supplies;

and the vagaries of the labor market, inspection follow-through, and professional practices. Thus a plumbing code utilized nationally would logically have varying regional emphasis on requirements for some performance characteristics.

In order to provide resource material for the use of code administrators in determining compliance and for the use of designers and installers in the selection of materials and equipment and in its fabrication and erection, codes generally reference existing standards. Such standards may cover such details as composition, dimension, and/or mechanical and physical properties of piping materials (e.g., pipe and fittings), fixtures, devices, and equipment used or installed in plumbing systems. The standards referenced in codes may also include documents promulgated by model codes or governmental bodies that describe acceptable installation procedures where this is important in evaluating the overall performance of a plumbing system. Many of the contemporary product standards provide means for identifying and specifying the product, and for guidance of the manufacturer in establishing quality control. Generally, these standards are not represented as performance standards, and do not include tests that can be directly related to the end-use service environment, although some of the technical parameters involved may be common.

When the language of standards specifies dimension, shape, materials, color, etc., for the production of components, they may be categorized as "design standards". Conversely, if the language identifies those characteristics of a product in the broadest terms available to meet the users' needs, they may be categorized as "performance-oriented standards".

Most of the existing product standards list minimum or maximum limits on dimension, weights, etc., together with tolerences. Such standards contribute to interchangeability among the lots of different product manufacturers.

The principal promulgators of standards in the United States are the American Society for Testing and Materials (ASTM), and the American National Standards Institute (ANSI). The U.S. General Services Administration (Federal Specifications), the Department of Housing and Urban Development (FHA UM Bulletins), other Federal Agencies, several technical societies, and numerous associations of manufacturers prepare and publish recommended standards which may subsequently be adopted by the larger consensus standards organizations.

The standards include material specifications for thermoplastic pipe and fittings and thermoplastic piping solvent cements, recommended methods of test, and recommended practices for design and installation. A comprehensive listing of current standards is given in the Appendix, Section 8.2.

Various organizations have contributed to the development of codes and standards. Principal contributions have been in the form of test reports, technical notes, engineering handbooks, specifications, and technical bulletins. An abbreviated compilation of such references is given in the Appendix, Section 8.3.

1.4 Overview of Program

The long-range objective of the program on criteria for pipng materials is to develop performance criteria for piping materials used in subassemblies and systems for residential plumbing. At the present time, codes emphasize acceptance of several specific materials such as steel, cast iron, and copper, and provide a schedule of materials that are acceptable to administrative authorities for use in cold water, hot water, and DWV transport systems. In instances where new materials such as thermoplastic piping are recognized by the plumbing code, such materials are generally required to conform to standards adopted by the industry; and to be identified as acceptable through

National Sanitation Foundation certification. Code administrators invaribly require of innovative proposals that design and installation procedures follow manufacturer's recommendations and in addition may require test data from the manufacturers to substantiate the proposals. Since codes depend heavily on a relatively long period of experience with traditional materials and with on-site construction techniques, some of the code stipulations may be considered overly restrictive or inappropriate for innovative piping systems.

The guide criteria for plumbing developed by NBS for the Operation BREAK-THROUGH program permitted greater freedom in materials and systems choices than does a typical code. It was found in that program that because the systems and the criteria for their evaluation were developed from existing technology, evaluation of the new piping methods suffered some of the same weaknesses inherent in the codes. Typically there still exists a need to clearly account for important aspects of service conditions such as in the interactions between the fluids transported and the different parts of plumbing assemblies, the chemicals and tools ordinarily used in maintenance, and the essential safety consideration relating to building fires.

Among the subjects needing study are (a) maintenance of the essential properties or functions of piping in response to internal mechanical or chemical action such as pressure, temperature, corrosion, etc., (b) maintenance of structural stability and strength in response to stress or movement in the piping induced by the flow of hot and cold water, (c) hydraulic efficiency (d) acoustical acceptability, (e) aging effects (f) spread of fire, smoke, and toxic gaseous products, (g) resistance to bursting and leaking of assemblies, and (h) the preparation of comprehensive criteria that take into account not only the performance characteristics of the materials in installed assemblies under service conditions, but also critical design and installation parameters that can effect system performance.

Objectives for the long-range NBS program include (a) the provision of performance criteria for piping materials as used for drain, waste, vent and water distribution systems in housing, (b) development of test procedures for the evaluation of piping, with an emphasis on thermoplastics, and (c) a determination under representative service conditions, of selected critical performance characteristics of a number of the innovative piping materials used or suggested for application in residential plumbing systems.

2. SUMMARY OF THE USE OF THERMOPLASTIC PIPING FOR RESIDENTIAL PLUMBING

2.1 Application of Various Thermoplastics in Plumbing Systems

A great variety of thermoplastic materials is theoretically possible depending on the chemical composition of the polymer, and on manufacturing conditions. The determinant features for application in plumbing systems are the transition temperatures where softening occurs, structural strength and stability, resistance to corrosion or abrasion, resistance to typical household chemicals, and cost to manufacture and to install. Some thermoplastic materials that are used for piping are listed in table 1. There are a variety of potential uses for thermoplastic pipe in housing including electrical conduit, service and distribution piping for fuel gas and water, and drain-waste-vent piping. This report is limited primarily to a review of information on uses for water-distribution and DWV piping in residential plumbing. The most common uses of thermoplastic piping materials in residential plumbing systems are the following:

ABS: for cold-water distribution within buildings, for exposed cold-water piping, for yard piping and service outside the building, and for DWV systems.

CPVC: for hot and cold water distribution within buildings, not widely used to date.

PE: for cold water distribution, cold-water for exposed piping, and for yard piping and service piping outside the building.

PVC: for cold-water distribution within buildings, for exposed cold-water piping, for yard piping and service piping outside the building, and for DWV systems, constituting in 1972 about 38% of thermoplastic DWV systems.

The extent of usage of thermoplastic piping is rapidly expanding, as may be seen from the following values contained in an AID report [3] published in 1969 and supplemented by data from Department of Commerce Current Industrial Reports M30F: In 1948, 0.5 million dollars; in 1957, 50 million; in 1967, 187 million, and in 1972, 548 million dollars. Approximately two-thirds of the thermoplastic piping produced in the United States is used for water supply and distribution and for DWV piping. Figure 1 illustrates the proportions for pipe use based on the 1972 production of 1,458 million pounds.

The rapid growth in the use of thermoplastic piping can be attributed mostly to the improvement in manufacturing techniques which have created materials with progressively greater impact strength, greater resistance to heat distortion, and improved consistency in the product. Continuing standardization and educational programs by manufacturers, and an increasing acceptance by designers, contractors and communities through a greater understanding of thermoplastic piping technology have also contributed to this growth.

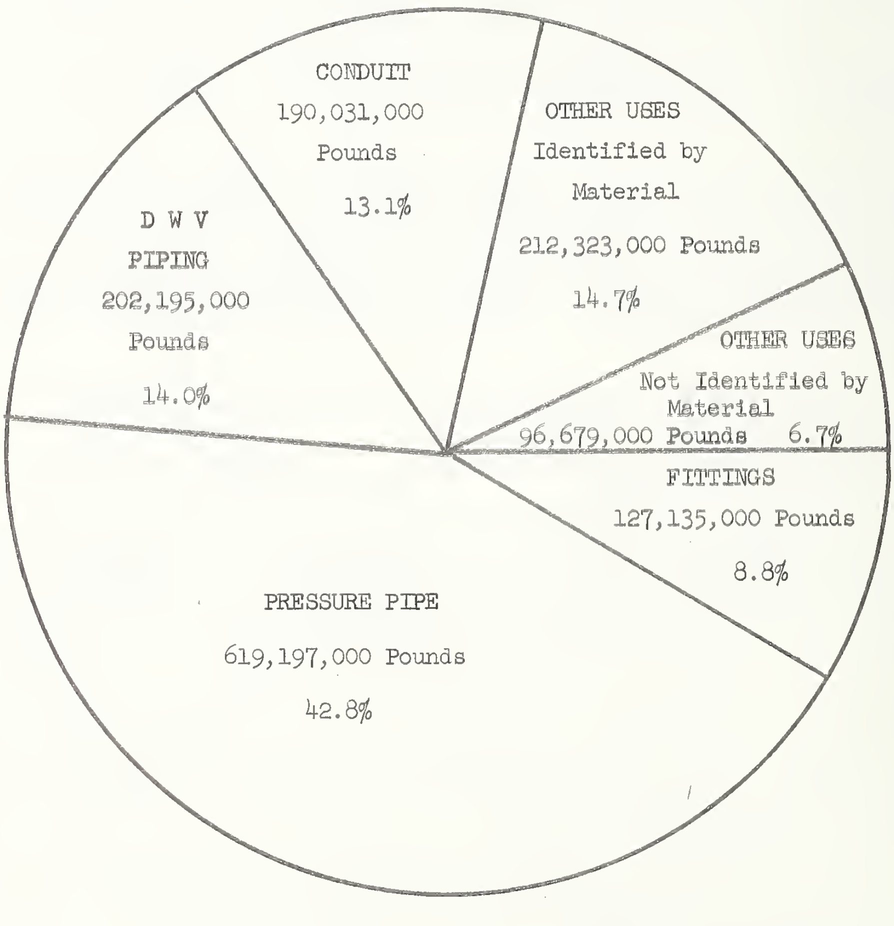

Figure 1. Production in the United States during 1972 of Thermoplastic Pipe, Tube and Fittings, Identified by End Use.

The generic term "plastic" has led many persons to think of thermoplastics as being a specific material with physical properties such as are associated with a particular metal. Users have become generally familiar with the thermosetting plastics materials, e.g., dinnerware that can be washed under boiling water or lighting fittings that can withstand the heat from lamps. They are often only vaguely aware that markedly different plastics, the thermoplastic materials, are used for piping in their homes, instead of the traditional metal piping.

Some guide or some educational program for the dwelling occupants would be an important step to protect thermoplastic piping from misuse and to provide guidance for proper maintenance. For example, in some cases certain household chemicals could be damaging if poured into the thermoplastic DWV system. The prolonged running of very hot water through the system could cause excessive temperature rise of some of the plastic material, which could result in permanent deformation of the pipe or fittings.

2.2 Potential Advantages and Disadvantages of Use of Various Materials

In evaluating the problems of thermoplastic piping in plumbing systems it is important to rate the piping by its performance in an operational system rather than to compare the properties of the plastics and metals used in the piping. It is a familiar advertising means for pipe manufacturers to extol the virtues of their product by comparing certain properties of their piping materials with those of other products instead of evaluating them against meaningful working criteria in a service environment. The point is that each material can have its own particular set of problems and <u>all</u> of them need to be resolved if the material is to be used successfully in a working system. With traditional materials, resolution of many problems has come about gradually with the development of improved techniques and products. With thermoplastics piping, the technology is still developing so not all problems of types traditionally requiring experience in their resolution have been settled to the collective satisfaction of all concerned groups.

The principal advantages and disadvantages of thermoplastic piping for plumbing are summarized as follows:

Potential Advantages (thermoplastic)

a) Lightweight material provides for easy handling by individual workmen and reduces dead-load forces on the structure.

b) Corrosion resistance to water and to the majority of household chemicals is high.

c) Deposits do not accumulate to the extent associated with some traditional piping materials.

d) Electrolytic action and electrical conductivity are insignificant which could reduce the problems of electrolytic corrosion.

e) During construction, fire hazards from torches used for the brazing or soldering of metal pipe and fittings are eliminated through the use of other means for joining thermoplastic pipe.

f) Sound transmission along the length of a thermoplastic pipe is low, due to its low stiffness, compared to metals.

Potential Disadvantages (thermoplastics)

a) There is a maximum service temperature for a particular thermoplastic which sets the upper limit to which the pipe may be heated without damage. When the pipe material is heated above this temperature, the pipe material will soften and deform; upon cooling it will harden to the deformed shape and dimensions. These critical temperatures for the thermoplastics considered here are near the temperature of boiling water; hence it is important to determine that the normal service temperature will be below the maximum service temperature. In addition, the strength decreases as the temperature increases, which is of particular importance in pressure piping. Therefore, both the service pressure and service temperature must be considered in specifying the appropriate material and the wall thickness of the pipe.

b) Movement of piping resulting from hydraulic loads and thermal effects is relatively high, compared to metals. This necessitates that special attention be given to installation details.

c) Mechanical cleaning to remove obstructions in drains and vents with such conventional equipment that includes power-driven auger, rodding, or scraping mechanisms may cause damage to the piping if care is not taken to avoid the use of some of the mechanisms used in cleaning metallic systems.

d) Control of the spread of fire, smoke, and toxic gases from plumbing chases or walls containing thermoplastic materials may require special attention to installation details.

e) The grounding of electrical appliances and electrical circuits must be accomplished via a separate conductor and ground spike, if thermoplastic water service piping is used instead of metal pipe.

f) If thermoplastics are to be exposed to the sun for long periods, they may need to be specially stabilized; otherwise ultraviolet radiation may cause degradation. Thus, the appropriate choice of material should be made.

g) Due to its light weight, thermoplastic piping offers little acoustical damping to airborne sound, thus special measures may be required to counteract any unpleasant sounds.

h) Because of the relatively short period of experience with thermoplastic piping for residential plumbing, compared to that with metals, and because of the unreliability and incompleteness of statistics on use experience, some degree of uncertainty exists regarding the long-term durability and the susceptability to bacteriological and biological attack.

Laboratory tests have produced chemically induced cracking (environmental stress cracking) of thermoplastics. This phenomenon is not well defined nor is its relative significance established in relation to thermoplastic piping systems in service. This is largely because of uncertainty as to the typical pattern of service exposure in relation to the circumstances under which stress cracking can be produced in the laboratory.

Many of the potential disadvantages in using thermoplastic piping systems in plumbing can be resolved with sensible design, assembly and usage. Expenses to overcome the disadvantages are not great if the housing design incorporates the requirements prior to construction. However, if ignored, the potential disadvantages can sometimes become real disadvantages.

There is considerable predisposition in the plumbing industry regarding the choice of piping materials. It is important for government agencies and for designers and specifiers to maintain a circumspect view over this controversial issue. To aid in reaching fair decisions, the following discussion is provided regarding the attributes of metal piping systems. These include cast iron, galvanized iron or steel, copper, brass, bronze, and stainless steel piping materials.

Potential Advantages (metals)

a) For metal piping, the structural strength is high and the dimensions change little over the normal range of temperatures for plumbing service.

b) Movement of the pipe from hydraulic loads and thermal effects is small which means that clearances need only be nominal and control of thermal expansion or contraction can readily be accomplished with standard techniques.

c) Since metals are non-combustible at the usual temperatures of building fires, toxic products are not produced although care is needed in the construction of plumbing chases and walls to control the spread of fire and the toxic products that come from other building materials that are combustible.

d) Susceptibility to bacteriological and biological attack is insignificant.

e) Grounding of electrical appliances and circuits is convenient as metals are conductors.

f) The heavy mass of cast iron or steel piping helps to dampen vibrations that could result in unwanted noise.

g) Durability varies with the metal selected for use. As a result of experience, adequate durability can be obtained by selecting the appropriate metal for a particular use.

h) Satisfactory cleaning procedures by mechanical or chemical means have been available for many years; however, some augers and chemicals can reduce the life of the pipe.

Potential Disadvantages (metals)

a) Corrosion may affect all metal piping to some extent. Copper may corrode particularly about brazed joints and may be attacked by urine in urinal drain piping. Stray electric currents moving along the pipe may cause corrosion at the place where the current enters the earth. Dissolved carbon dioxide in the water causes corrosion of ferrous as well as non-ferrous pipe. Iron pipe readily corrodes forming a pipe-clogging rust scale, and deep pitting may occur particularly with acid waters. Joints of steel pipe may fail in a corrosive environment (e.g., burial in a corrosive soil) because the protective galvanizing is removed in the threading operations. Protective coatings may be required in such cases.

b) Assembly of piping can be tedious with some of the jointing techniques. Pipe and fittings may be relatively heavy necessitating helpers for each plumber.

c) The space required to accommodate some of the metallic piping may create problems due to large overall outside diameter and bulky joints, particularly where reduced-sized structural elements are to be used.

d) For heavy metal pipes, the structural loading is particularly high under seismic conditions.

e) Deposits may accumulate from corrosion, fluid suspensions, and chemical precipitation to an extent that they can seriously reduce inside diameter and the hydraulic flow, particularly in the case of ferrous piping in "hard" waters.

f) Contamination of water may occur from lead soldering, copper corrosion, and rusting. This potential problem is strongly influenced by water composition and temperature.

g) Condensation of moisture from the air on cold pipes increases exterior corrosion and promotes damp conditions for growth of fungus and icing of poorly insulated cavities. Similarly, the high thermal conductivities of metal pipes contribute to frost closures of vent terminals in northern latitudes.

h) Sound transmission by conduction is high in stiff metal systems, thus knocking initiated at one point can be transmitted throughout the house.

Many of the potential disadvantages of metallic piping for plumbing can be overcome through adherence to generally accepted good practice in design and installation. For example, where water characteristics are adverse, a water quality control program or an alternate choice of material can provide an acceptable solution. Sound transmission can be reduced through the use of resilient gaskets and supports, and exterior condensation can be reduced through use of better insulation and humidity control.

2.3 Code Approvals and Restrictions for Use

Thermoplastic piping in residential plumbing systems has for a long time been without general acceptance by code authorities because metallic piping was already acceptable and available, whereas thermoplastic piping was questionable and unproven. Slowly a body of supporting data has been accumulated so that in the past few years the material has been accepted for certain applications. For drain, waste and vent systems (DWV), a recent survey [4] has reported that acrylonitrile-butadiene-styrene (ABS) and poly(vinyl chloride) (PVC) are now permitted for single family housing construction by more than 86% of local codes in the United States. Previous samplings by the same source [5] had shown 86% in 1973, 77% in 1972, 71% in 1971, 50% in 1970 and 25% in 1969. In addition, it was reported that ABS and/or PVC is now permitted by 70% of local codes for DWV in low-rise apartments, and 49% in high-rise structures.

The increase in the number of approvals of plastic pipe is a reflection of the changes being made in the model codes upon which many local codes are based. In the previous survey (1973) referenced above, code authorities were requested to indicate whether or not their plumbing code was based on or identical with any of the model codes. From the 2,250 replies to the questionnaire, it was learned that 30% were using NSPC, 22% UPC, 17% SSPC, and 15% BPC.

Acceptance of thermoplastic piping for water supply is more limited than for DWV piping. Where allowed within the building, it is for the most part restricted to CPVC and when allowed underground outside the building line, PE is frequently used.

Table 2 provides a summary of the current status of approved usage (by city codes) of four types of plastic pipe for water and DWV systems.

In table 3 a summary has been prepared to show the current limitations in model codes and similar documents on use of plastic pipe for water supply and for DWV applications. Operation BREAKTHROUGH Guide Criteria were intended only for construction placed on the OBT Prototype Sites, in accordance with the agreement between HUD and the local code authorities. Operation BREAKTHROUGH criteria basically neither required nor excluded the use of a particular material. The performance concept is that any material may be used provided that it can be shown to meet the performance requirements of the system for a reasonable life expectancy. In the case of thermoplastic pipe, it is difficult to establish that performance requirements have been met because a number of unresolved issues or questions still exists.

2.4 Unresolved Issues and Open Questions

Among the more prominent unresolved issues affecting the evaluation of innovative piping materials are the following:

- The definition and utilization of a harmless and effective process or procedure for cleaning thermoplastic (or other innovative) piping.
- Durability of material in a typical service environment, as related to possible aging effects.
- Resistance of piping material to household chemicals and to environmental stress cracking.
- Toxicological effects of material when used for water supply piping.
- Behavior of thermoplastic (or other organic) piping material in a burning room or building.
- Dimensional stability of material when subjected to typical thermal loads over a period of time.

Among other matters for which concern has been expressed are acoustical isolation, biological and bacteriological attack, and the effects of thermal expansion and contraction. However, this study suggests that these are secondary issues and can be controlled satisfactorily through application of known good practice in design and installation.

3. EXISTING CRITERIA AND PERFORMANCE DATA FOR THERMOPLASTICS PIPING IN PLUMBING SYSTEMS

3.1 Toxicological Considerations

The World Health Organization has published limiting values for the contaminants in potable water [6] and the U.S. Public Health Service (PHS) has published standards for drinking water [7]. In 1951 the National Sanitation Foundation (NSF) undertook a program for determining whether the potability of drinking water carried by thermoplastic piping was adversely affected by the piping materials. Subsequently the NSF program was expanded to establish whether manufactured lots of thermoplastic piping (pipe and fittings) meets the generally recognized physical standards for thermoplastic piping — in addition to the health standards. The NSF seal of approval is permitted on a manufacturer's product tested and found to comply with such standards as long as tests made on samples taken at the factory on unannounced visits indicate that the product continues to comply. Toxicological consid-

Table 2. Matrix Presentation of Plumbing Code Provisions, in 68 Cities Throughout the U.S., Regulating Selected Uses of Four Thermoplastic Piping Materials (Excerpts from Tabulation Prepared by DE/Journal and Printed in the March 1973 and March 1974 Issues). 4,5/

City	PVC Plastic DWV	ABS Plastic DWV	PE Plastic Water Pipe	CPVC Plastic Water Pipe
Albany, N.Y.	N	N	N	N
Baltimore, Md.	L[1]	L[1]	X	X
Billings, Mont.	L	X	C	X
Boise, Idaho	S	S	X	X
Boston, Mass.	S	S	X	X
Buffalo, N.Y.	A	G	C	O
Charlotte, N. C.	A	A	P	O
Chicago, Ill.	X	X	X	X
Cincinnati, Ohio	A	A	X	X
Cleveland, Ohio	G	S	G	H
Colorado Springs, Colo.	A	A	P	H
Columbia, S.C.	A[3]	A[3]	C	O
Columbus, Ohio	A	A	C	X
Dallas, Texas	A	A	P	O
Dayton, Ohio	A	A	C	X
Denver, Colo.	L	L	X	X
Detroit, Mich.	A	A	X	X
Dubuque, Iowa	G	G	X	X
Duluth, Minn.	G[4]	G[4]	P	X
Durham N. C.	A	A	C	O
Elmira, N. Y.	G	X	X	X
Flint, Mich.	A	A	C	O
Fort Worth, Texas	G	X	X	X
Fresno, Calif.	S	S	C	O
Grand Rapids, Mich.	A	A	X	X
Honolulu, H.I.	S	S	C	O
Jacksonville, Fla.	A	A	C	X
Kansas City, Mo.	A	A	X	X
Las Vegas, Nev.	S[5]	S[5]	C	O
Little Rock, Ark.	S	S	P	O
Los Angeles, Calif.	L	L	P	H
Madison, Wis.	A	A	P	H
Memphis, Tenn.	L	L	C	X
Miami, Fla.	A	A	X	O
Milwaukee, Wis.	L[5]	L[5]	C	H
Minneapolis, Minn.	S	S	P	X
Mobile, Ala.	A[3]	A[3]	C	X
Montgomery, Ala.	L	L	X	X
Nashville, Tenn.	A[3]	A[3]	X	X
Newport News, Va.	L[1]	L[1]	C	C
New York, N.Y.	L	L	X	X
Oklahoma City, Okla.	G[4]	G[4]	C	C
Philadelphia, Pa.	L	L	C	X
Phoenix, Ariz.	S	S	P	O
Pittsburgh, Pa.	A	A	X	X
Pontiac, Mich.	A	A	X	X
Portland, Me.	S	S	C	H[5]
Portland, Ore.	S	S	X	X
Providence, R. I.	G	G	X	H
Richmond, Va.	L[2]	L[2]	X	X
Rockford, Ill.	A	A	C	H
St. Louis, Mo.	L	X	C	X
St. Petersburg, Fla.	S	S	X	X
Salt Lake City, Utah	L[1]	L[1]	P	X
San Francisco, Calif.	S	S	X	X
Saratoga, Fla.	L[1]	L[1]	P	O
Shreveport, La.	A	A	C	O
Tacoma, Wash.	L[1]	L[1]	P	X
Tampa, Fla.	A[3]	A[3]	X	O
Toledo, Ohio	A	A	X	X
Tucson, Ariz.	S	S	C	X
Tyler, Texas	X	X	X	H
Washington, D.C.	A	A	X	H
Wheeling, W. Va.	A	A	C	O
Wichita, Kansas	S	S	P	O
Wilmington, Del.	L	L	X	X
Winston-Salem, N.C.	A	A	C	X
Youngstown, Ohio	A	A	X	X

A - Approved for all types of structures above and below ground

C - Commercial or premium grade approved for use outside building line.

G - Approved for above-ground use only

H - Approved for use in hot and cold water supply lines within buildings.

L - Approved for use in single-family homes and low rise apartments

N - Not covered by code.

O - Approved for below-ground use outside building line

P - Premium grade only approved for use outside building line

S - Approved for use in single family and (in some codes) 2-family homes only

X - Prohibited

1 - Also approved for use in commercial structures

2 - Also permitted in high-rise apartments

3 - Up to 60 feet in height

4 - Residential and low-rise apartments

5 - Cold water only

erations involve the chemical substances from the thermoplastic piping that might dissolve into the water and render the water harmful to health. The concentrations of the deleterious substances are monitored to ensure that they fall below those established by the U.S. Public Health Service.

Potential organoleptic problems of water conveyed through the thermoplastic piping relate to the appearance, taste and odor which could render the water unacceptable for people's use. Criteria for this appraisal are derived from the U.S. Public Health Service Standard. Both kinds of piping, the commonly used thermoplastics (ABS, CPVC, PE, PVC) and the metal piping (copper, galvanized steel) meet the PHS Standards as measured by the NSF organoleptic test methods [8].

In PVC pipe manufacture, stablizers are needed to assure a product with good resistance to aging, a process which can particularly affect the stress characteristics and the impact resistance. These stablizers are simple compounds such as lead carbonate or similar compounds containing cadmium, calcium, tin or zinc. Lead stablizers are widely used in PVC pipe manufacture throughout the world, but in the U.S. such pipe does not pass the NSF test requirement. Lead stablizers in thermoplastic piping are not restricted by the existing piping standards but by the PHS criteria that limits the concentration of lead in drinking water to a maximum of 0.05 mg/l using the stringent NSF test procedures.

The concern over extractable lead in PVC pipe stems from the knowledge that ingestion of soluble lead compounds results in the deposition of metallic lead in the bones. Since lead is not readily eliminated by normal bodily functions, ingestion of small quantities over a prolonged period of time may result in a cumulative effect that can lead to lead poisoning. However, because the quality of water can be monitored and kept within precise bounds by the waterworks chemist, the PHS has established standards for the lead content of drinking water based on rather precise chemical tests.

3.2 Resistance to Chemical Attack and Stress Cracking

The chemical attributes of the piping of a plumbing system are those that resist the effects of acids, alkalies, and organic solvents upon the piping material. Water contains a variety of chemicals to make it potable and soft, such as chlorides, fluorides, carbonates, polyphosphates, hypochlorites, etc., depending on the source and treatment. Chemical composition of household wastes vary widely because of variations in chemical composition of the water supply, the addition of normal kitchen, laundry and bathroom waste, and the introduction of household cleaners, garden sprays, oils, paints, and medical or cosmetic preparations that are sometimes disposed of through the plumbing system.

Some household cleaning agents and solvents will damage thermoplastic piping if not diluted. The effects can range from a surface softening to a dissolving of the material if the period of contact is long and the concentration is high. In the use of such materials, care should be taken to avoid disposal in a thermoplastic drainage system, or else they should be adequately diluted and flushed through the system with copious amounts of water. Otherwise, some attack may occur on ABS, and to a lesser extent on PVC. Such attack would be most likely in small-diameter fixture traps. Among the cleaning agents and solvents that could damage thermoplastic piping are:

acetone - used for cleaning tools and hands, for paint preparation or removal

aqua ammonia (ammonium hydroxide) - generally refers to concentrated solutions that are several times stronger than that used in window and floor cleaners and as a bleach

Table 3. State-of-the-Art Survey of Model Plumbing Codes and Similar Documents for Limitations on Use of Thermoplastic Pipe for Water Distribution and for DWV Applications.

Code or Criteria 1/	DWV Piping Above Ground	DWV Piping Below Ground	Water Distribution Piping Cold	Water Distribution Piping Hot
1. Model Plumbing Codes 2/				
National (NPC) ASA A40.8 - 1955 (Under Revision)	N/A 3/	N/A 3/	N/A 3/	N/A 3/
Basic (BPC) BOCA 1970 Supplement 1973	ABS, PVC 4/	Schedule 40 4/ plastic	Plastic 4/ Cold Water	CPVC 4/
Uniform (UPC) IAPMO 1973	ABS, PVC 5/ (2 stories)	ABS, PVC 5/ (2 stories)	N/A 5/	N/A 5/
National Standard (NSPC) PHCC 1971 ASPE - PHCC 1973A	ABS, PVC 6/ Schedule 40	ABS, PVC 6/ Schedule 40	Approved 6/ plastic	Approved 6/ plastic
Southern Standard (SSPC) SBCC 1971 Revisions 1974	ABS, PVC 7/ (60' height)	ABS, PVC 7/ (60' height)	CPVC 7/	CPVC 7/
Canadian (CPC) NRCC 1970 Revisions 1973	ABS, PVC 8/ (36' height)	ABS, PVC 8/ (36' height)	CPVC 8/	CPVC 8/
2. HUD Minimum Property Standards 9/				
One and Two Family Housing	ABS, PVC	ABS, PVC	CPVC	CPVC
Multi-Family Housing	ABS, PVC (6 stories)	ABS, PVC	N/A	N/A
Rehabilitation of Housing	ABS, PVC	ABS, PVC	CPVC	CPVC
3. Operation BREAKTHROUGH Guide Criteria 10/				
Single Family Housing	ABS, PVC (3 stories)	ABS, PVC	CPVC	CPVC
Multi-Family Housing	ABS, PVC (3 stories)	ABS, PVC	CPVC	CPVC

1/ All major codes have a provision for "approval" of alternate materials which states, for example, that "Provisions of this code are not intended to prevent the use of any material, device, . . . provided such alternate has been approved by the Administrative Authority . . ." Quite often such approvals are at best difficult to obtain.

2/ See section 8.1 for addresses of model-code sponsors.

3/ Use of plastic pipe is not authorized , N/A

4/ From paragraph P-405.13: The water distribution system shall be . . . or . . . CPVC hot and cold water plastic pipe or plastic cold water pipe.

From paragraph P-405.21: Above Ground Piping Within Buildings --- Soil and waste piping . . . shall be . . . or . . .ABS plastic or PVC plastic pipe.

From paragraph P-405.22: Underground Building Drains --- All underground building drains shall be . . . or Schedule 40 plastic pipe.

From paragraph 405.31: Above Ground Venting --- Vent piping installed above ground shall be . . . or . . . ABS plastic pipe or PVC plastic pipe.

From paragraph P-405.32: Underground Venting --- Underground vent piping shall be of . . . (or) . . . Schedule 40 plastic pipe or .....

Each of the above paragraphs have the additional requirement that: "All plastic pipe shall be marked with the appropriate identification of a quality control agency recognized in duly authenticated reports from

4/continued
Building Officials and Code Administrators International.

5/ Section 401(a) : Drainage pipe shall be . . . ABS, PVC or . . . except ABS or PVC installations limited to residential construction not more than two stories in height.

Section 401(b) Drainage fittings shall be . . . ABS, PVC or . . . having a smooth interior waterway of the same diameter as the piping served and all such fittings shall conform to the type of pipe used.

Sections 502 and 503: Vent pipe and . . . vent fittings . . . shall be . . ABS, PVC or other approved material.

Installation standards IS-5-71 and IS-9-71 identify requirements that are in addition to the following:

Section 316(a)(6) Plastic pipe shall be maintained in the straight alignment.

Section 316(b)(7) Plastic pipe shall be supported at not to exceed four(4) feet.

Section 803(f) Joints in ABS and PVC pipe shall be made as provided in 802(m).

6/ Section 11.1.1 : Soil and waste piping above ground in buildings shall be . . . or . . . ABS or PVC Schedule 40 or heavier plastic pipe.

The same materials are permitted in the following uses:
Section 11.1.2 : All underground building drains . . .
Section 12.1.1 : Vent piping above ground in buildings . .
Section 12.1.2 : All underground vent piping . . .

Section 10.10.2 : Water distribution pipe shall be . . .

6/continued

. . . or approved plastic pipe. From section 3.1.3 : A material shall be considered approved if it meets one or more of the standards cited in Table 3.1.3 . . . and in the case of plastic pipe, also the listed standard of the National Sanitation Foundation.

7/ Section 506.7 --- Plastic Pipe and Fittings for Drain Wastes and Vent: For plumbing drainage, waste and vents both above and below ground, indirect wastes and storm drains, for buildings not exceeding (60)feet in height.

Installations shall conform to installation procedures of ASTM D2661-1973 for ABS or ASTM D2665-1973 for PVC, except where conditions of the SSPC are more stringent in which case they shall apply.

There shall be no co-mingling of the two materials in the same system except through proper adapters. In all cases approved solvent cement designated for the particular material shall be used.

From Table 505: For water distribution piping (above ground) Chlorinated poly(vinyl chloride) CPVC, ASTM D2846-1970 with NSF seal of approval.

Section 1212.1(a) Above Ground --- Materials for water distribution piping and tubing shall be . . .or . . . chlorinated poly(vinyl chloride) (CPVC), all to be installed with the appropriate approved fittings.

8/ Section 7.2.5.8(3) Plastic pipe shall not exceed 36 feet in stack or vent height.

Section 7.2.5.8(4) Requirements for plastic piping in relation to fire safety shall conform to Sentence 3.1.7.7(2) and Article 9.10.9.25.

Section 3.1.7.7(2) Plastic drain, waste and vent pipe shall not be used in systems that pass through or are located in a required fire separation.

Section 9.10.9.25 Combustible drain, waste and vent piping shall not be used in a plumbing system within a building where part of the system is located within or passes through a fire separation, except that where drain, waste or vent piping penetrates through a vertical fire separation, the piping on one side of the separation may be combustible provided the combustible piping is not located in a vertical shaft or in a fire separation.

Section 7.2.5.9(1) CPVC hot and cold water pipe, fittings and solvent cements shall conform to CSA B137.6-1971 "Chlorinated Poly(vinyl chloride) (CPVC) Plastic Piping for Hot and Cold Water Distribution Systems".

Section 7.2.5.9(2) CPVC pipe and fittings may not be used in a system where the design water temperature may exceed 180°F or if the design pressure may exceed 100 psi.

Section 7.2.5.8 Plastic pipe, fittings and solvent cement used inside a building, in a drainage or venting system shall conform to (a) CSA B181.1-1967 (ABS) and (b) CSA 181.2-1967 (PVC).

9/ The limitations on the use of PVC and ABS are stated in "Use of Materials Bulletins" UM-53a and UM-54 respectively. The use is limited to low structures so that for multi-family structures the height may not exceed six stories, but when used for horizontal branches it may be used for any structure.

Limitation on use of CPVC for water distribution is stated in "Use of Materials Bulletin" UM-61. It may be used in the new construction of single and double family units. It may also be used in rehabilitated structures not exceeding six stories in height.

10/ Use of Schedule 40 ABS or PVC DWV plastic pipe is limited by the following considerations :

a. ABS not to be used in multi-family high rise.
b. For sizes 2" or less neither ABS or PVC shall be used for drains that can receive hot water at temperatures in excess of 165°F.
c. Any plastic pipe must satisfy Operation BREAK-THROUGH fire criteria.
d. Adequate provision shall be made to accomodate thermal expansion.
e. National Sanitation Foundation certification or equivalent is required.
f. Design and installation techniques shall be in accordance with generally accepted standards and industry recommendations.
g. Pipe and fittings shall be appropriately marked to show NSF approval, applicable standards and manufacturer's name.
h. All pipe, fittings, transition fittings, cement, hangers, and supports, etc. shall meet applicable generally accepted engineering practice.
i. Acoustic control shall be provided in accordance with generally accepted engineering practice.

Schedule 30 has certain additional limitations :

a. Not to be used for horizontal drains except water closet branches.
b. Wall thickness must be at least 0.125 in. in the 3-inch size, 0.133 in. in the 4-inch size and 0.162 in the 6-inch size.
c. Rationale and supporting data shall be provided for proposed applications in specific housing systems.

For use below ground, Schedule 40 ABS or PVC plastic pipe is limited as follows :

a. Detailed engineering analysis of soil pressures and supporting strength required, for as-installed condition.
b. Requirements listed for above-ground use of Schedule 40 plastic pipe at (e), (f), (g) and (h) apply also to below-ground use.

Schedule 40 CPVC may be used above ground for water distribution with the following limitations :

a. Limited to systems with storage-type water heater in living unit, thermostatted to limit water temperatures to 165°F or less; or
b. to systems with non-recirculating central water heater thermostatted to limit water temperatures to 165°F or less; to branch piping only in systems with recirculating central water heater thermostatted to limit water temperatures to 165°F or less and with at least 12 inches of metal connector pipe at riser; or
c. to systems with recirculating central water heater thermostatted and provided with automatic fail-safe shutoff valving to prevent water temperature rising above 140°F at any point in the water distributing system.
d. Waterhammer protection required (either by limiting design velocities to 5 ft/sec, by the use of slow-closing valves, or by the use of air chambers or shock arrestors designed to limit over pressure to 150 psi or less). Maximum static pressure must be limited to 70 psi.
e. NSF certification for use with potable water required.
f. Adequate provision shall be made to accomodate thermal expansion and contraction.
g. Design and installation techniques shall be in accordance with generally accepted standards and industry recommendations.
h. Pipe and fittings shall be appropriately marked to show NSF approval, applicable standards, and manufacturer's name.
i. All pipe, fittings, transition fittings, cements, hangers, supports, etc., shall meet applicable generally accepted standards.
j. Rationale and supporting data shall be provided for proposed applications in specific housing systems.

benzene (benzol) - used in paint and varnish removers

chlorinated hydrocarbons - used in solvents, dry cleaning fluids, and insecticides

ethyl alcohol - used in beverages and in solvents

gasoline - used as a motor fuel also used for its solvent action

iodine, tincture of - is a caustic antiseptic used for first aid, normally available only in 1- or 2-oz. containers.

isopropyl alcohol - used in solvents and as a rubbing alcohol

linseed oil - used in paints and varnishes as a drying oil

methyl alcohol - used as a solvent in paints, varnishes and shellacs

naphtha - used in dry cleaning fluids, paint removers, and solvents

sodium hydroxide (lye) - used in powder or liquid form for drain cleaning

sodium hypochlorite - a powder or liquid bleach used for laundry

toluol (toluene) - a solvent less toxic and less flammable than benzene

turpentine - used in paint as a drier or thinner, also as a solvent in household uses.

Table 4 has been prepared from information tabulated in Modern Plastics Encyclopedia to show in a general way the effects of acids, alkalies, and organic solvents on four plastic materials.

3.3. Thermal Characteristics

The thermal characteristics of thermoplastic piping materials differ from those of metallic materials, such as copper or steel, in the extent of the temperature range over which the materials have practical application. For the thermoplastic piping materials currently on the market, the upper limit of the allowable working range extends only slightly beyond the temperature of boiling water (less for some materials). V. V. Korshak [9] compiled a comprehensive treatise which gives guidance to researchers who seek to extend the allowable working temperature range of thermoplastic material to higher values. Some such materials are available now, but the cost of the material and the cost of installation keep them from being competitive with the leading materials currently on the market.

The upper limits in the usable temperature range may be found in handbooks in several forms. One, resistance to heat °F continuous, identifies the maximum temperature to which an unstressed plastic material can be subjected for prolonged periods of time with reasonable assurance that no significant changes in its properties will occur. Above this temperature changes may be expected to occur in color, dimension, or mechanical property. Another form, deflection temperature, is defined by the procedure of ASTM D648. The test is made at two stress levels, 66 psi (0.46 MPa) and 264 psi (1.82 MPa). It is not intended to be a direct guide to high temperature limits for specific applications but it may be useful for comparing the relative behavior of various materials in these test conditions. Thermal expansion, thermal conductivity, and specific heat are three other parameters that help characterize the thermal qualities of thermoplastic pipe. Table 5 has been prepared to show these thermal parameters for four thermoplastic

Table 4. Comparison of the effects of acids, alkalies, and organic solvents on four piping materials (compiled from data tabulated in the 1974-1975 Modern Plastics Encyclopedia*)

Piping Material / Solvent Effect	Acrylonitrile-butadiene-styrene (ABS)	Chlorinated Poly(vinyl chloride)	Polyethylene (PE)	Poly(vinyl chloride) (PVC)
Effect of weak acids	None	None	Very resistant	None
Effect of strong acids	Attacked by concentrated oxidizing acids	None	Attacked slowly by oxidizing acids	None to slight
Effect of weak alkalies	None	None	Very resistant	None
Effect of strong alkalies	None	None	Very resistant	None
Effect of organic solvents	Soluble in ketones esters, and some chlorinated hydrocarbons	Resists most	Resistant below 80°C	Resists alcohols aliphatic hydrocarbons and oils. Soluble or swells in ketones and esters. Swells in aromatic hydrocarbons

*Modern Plastics Encyclopedia, October 1974 issue of Modern Plastics Magazine, McGraw-Hill Inc., New York, New York.

piping materials.

Data such as the above provide guidance for the selection of piping where there is a high-level of certainty that, in service conditions, the recommended temperature limit will not be exceeded or even approached closely. However, because there are many ways that malfunctioning of valves or other system components can cause unexpected high temperatures in the piping system, there are other parameters that must be evaluated.

One such parameter is <u>creep</u> which is generally considered to be a time-related parameter, but the magnitude increases with the temperature level. Another parameter, <u>stress-relaxation</u>, is concerned with the fact that at time of manufacture, pipe and fittings may develop high internal stresses. Relaxation of such stresses may occur at temperatures approaching those to which the material was subjected during the molding and cooling processes, when stresses may be introduced, and could result in unacceptably large dimensional changes particularly in the case of pipe fittings.

Although ASTM D 674-56 (1969) [10] is concerned with creep and stress-relaxation, it gives only broad considerations to be followed when defining such test procedures. A very real need exists to evaluate the residual stress in pipe and fitting after manufacture and the extent to which stress-relaxation may impose unexpected forces on joints and mounting configurations. No such test procedures now exist.

3.4 Structural Strength and Integrity

A structural evaluation of a thermoplastic water distribution system or DWV system considers the system's ability to perform design functions under the imposed service conditions over a planned service life span. The structural system is composed of the pipe, fittings, joints, and hangers or supports, while the principal structural service conditions include line pressure, pressure surges, and the weight of pipe and contents. The effects of the interaction between the components in the system and the service conditions are measured in terms of the actual performance over the service life for the system. Durability and essential functions may be affected by the thermal or chemical environment, or by aging. These are discussed elsewhere in this paper.

A review of publications from the National Academy of Sciences (BRAB), the Plastics Pipe Institute, and the American Society for Testing and Materials along with literature from the manufacturers and trade journals has indicated that much information is available to aid in the determination of structural adequacy of thermoplastic water distributing and DWV systems; but needs to be assembled and made available in improved format to those who specify, design and install, and to those who determine acceptance.

Traditionally, domestic plumbing systems have been constructed with piping materials that exhibit essentially constant properties throughout the range of temperatures expected during service. These properties, in general, also remain constant with time although the pipe itself may deteriorate from corrosion processes and eventually fail structurally. Any one of the following is considered to be a structural failure: bursting; joint leakage or weepage; permanent change in dimensions; or sag or angular rotation to the extent that hydraulic capacity, drainability or acoustic acceptability are adversely affected. The design for utilizing traditional materials can be based almost solely on the assumption of constant hoop, beam, and ring-deflection strengths, utilizing an allowance for loss of strength due to corrosion, threading, etc. However, for thermoplastic systems which utilize a material whose properties may not remain constant with time or temperature, considerations of strength as a function of temperature and possibly aging

Table 5. Values of selected thermal characteristics for four thermoplastic piping materials (data is based on information found in the Plastic Properties Chart of the 1974 - 1975 Modern Plastics Encyclopedia*)

Thermal Characteristics / Piping Materials	Resistance to Heat (continuous)	Deflection Temperature 66 psi Fiber Stress	Deflection Temperature 264 psi Fiber Stress	Coefficient of Thermal Expansion	Coefficient of Thermal Conductivity	Specific Heat
	°F	°F	°F	$\frac{10^{-5}}{°F}$	(Btu/hr/sq. ft/°F)-ft	Btu/lb/°F
		ASTM D-648	ASTM D-648	ASTM D-696	ASTM C-177	
ABS -						
Extrusion Grades	140 - 200	170 - 245	170 - 225	3.3 - 7.2	0.109 - 0.194	0.3 - 0.4
Molding Grades						
High Impact	140 - 210	210 - 225	200 - 218	5.2 - 7.2	0.109 - 0.194	0.3 - 0.4
High Heat Resistance	190 - 230	225 - 252	215 - 245	3.3 - 5.2	0.109 - 0.194	0.3 - 0.4
Medium Impact	160 - 200	210 - 227	199 - 221	4.4 - 5.6	0.109 - 0.194	0.3 - 0.4
Flame Retardent	130 - 180	199 - 245	186 - 215	3.6 - 5.3	0.109 - 0.194	0.3 - 0.4
CPVC -	230	215 - 247	202 - 234	3.8 - 4.2	0.080	0.33
PE -						
Low Density	180 - 212	100 - 121	90 - 105	5.6 - 12.2	.194	0.55
Medium Density	220 - 250	120 - 165	105 - 120	7.8 - 8.9	.194 - .242	0.55
High Density	250	140 - 190	110 - 130	6.1 - 7.2	.267 - .300	0.55
PVC -						
Rigid	130 - 175	135 - 180	140 - 170	2.8 - 5.6	0.085 - 0.121	0.25 - 0.35

* Modern Plastics Encyclopedia, October 1974 issue of Modern Plastics Magazine, McGraw - Hill Inc., New York, New York.

should be included in the design.

Since the dead-load weight of the pipe and the weight of the water or waste materials being conveyed impose a structural load on the system, suitable supports and hangers must be provided to control movement and maintain structural adequacy. Movement can occur in the system from such actions as the turning of a faucet or the operation of a solenoid valve, changes in direction of moving water, water hammer action, thermal expansion, or creep. When hangers and supports do not permit axial movement the effect on a system constructed with thermoplastic materials can be quite different from that in a system constructed with traditional materials because of the higher coefficients of thermal expansion for thermoplastics (and sometimes creep also).

One recommended practice for support of a system [11] points out that the hangers should never be clamped to the piping in a manner as to prevent axial movement of the pipe due to thermal expansion. This report also suggests that (1) the spacing and location of supports should take into account the pipe diameter, wall thickness and temperature conditions, and (2) horizontal or vertical runs of piping should be supported at intervals of not more than every 8 feet,[3/] near the ends of branches, near changes in direction, and near ends of runs in order to provide sufficient rigidity to the system. Furthermore, the actual spacing of the hangers should limit vertical deflection ("sag") between supports to a maximum of 1/2 inch under service temperature and hydraulic conditions (equivalent to a reduction of 50% of normal design slope with supports 4-feet apart). Support at 4-foot intervals for both horizontal and vertical runs of thermoplastic DWV piping is required by the model plumbing codes [See Section 8.1]. Other sources suggest for water distributing piping 2 inches or less in diameter, a maximum spacing of 3-feet (1m) [12] or 32 inches [13] with the latter figure being related to attachment to floor joists spaced at 16 inches on centers. It is possible that even though hangers properly designed and installed might allow for thermal expansion, the location of hangers too close to fittings, or fittings too close to structural elements, could produce stress and possible deleterious effects of repeated stressing and flexing at changes in direction. Several ASTM specifications [12, 14, 15] provide current generally-recognized criteria for supporting and attaching thermoplastic piping.

Currently, the recommended procedure [16] for design of a thermoplastic pressure pipe system is to use a hydrostatic design stress based on applying a service (design) factor to the long-term hydrostatic strength of the pipe. The long-term hydrostatic strength is the estimated circumferential stress that when applied continuously will produce failure in the pipe at 100,000 hours (11.4 years) at a specified temperature.

The service (design) factor is a positive number less than 1.0 [16] which takes into consideration certain variables together with a degree of safety appropriate to the particular pressure piping installation. Such service (design) factors are selected by the design engineer after he has evaluated fully the service conditions for the piping and the engineering properties of the specific plastics that he has been considering.

For a selected plastic piping material, the long-term hydrostatic strength is determined by standard test procedures under carefully-controlled temperature conditions. One such temperature is the Standard Laboratory Temperature (23°C or 73.4°F). Having obtained the hydrostatic strength at one temperature, additional values for other temperatures must be obtained by the same test procedures. Such values can only be obtained on the basis of direct measurement or interpolation from hydrostatic strength/temperature data in the range of the anticipated application.

3/ The referenced report was concerned with a wide range of diameters, in applications emphasizing relatively large sizes.

One manufacturer of CPVC has provided the data in table 6 which lists the minimum hydrostatic hoop stress for failure at 100,000 hours for CPVC at different temperatures. As the temperature increases, the hydrostatic hoop stress diminishes.

Table 6. Manufacturer's Test Data Showing for Six Temperature Levels the Minimum Hydrostatic Hoop Stress that Would Produce Failure at 100,000 Hours of Stress in CPVC Pipe.

Temperature	Hydrostatic Hoop Stress
73°F (22.8°C)	4,000 psi (27.58 MPa)
100°F (37.8°C)	3,200 psi (22.06 MPa)
120°F (48.9°C)	2,500 psi (17.24 MPa)
140°F (60.0°C)	2,000 psi (13.79 MPa)
180°F (82.2°C)	1,000 psi (6.89 MPa)
210°F (98.9°C)	630 psi (4.34 MPa)

In ASTM D 2846, table A1 gives hydrostatic design stresses and pressure ratings for CPVC 4120, SDR 11, hot water distribution systems. At 73.4°F (23°C) the hydrostatic design stress is 2000 psi (13.79 MPa) and the pressure rating for water is 400 psi (2.76 MPa) whereas at 180°F (82.2°C) the hydrostatic design stress is 500 psi (3.45MPa) and the pressure rating for water is 100 psi (0.69MPa).

By an extrapolation of data using log stress - log time linear regression computations, service life for plastic pipe is predicted to last far beyond the life span of average installations. A commonly used value is 50 years for which period the computations indicate that by lowering a continuously applied internal stress in the pipe by less than 10 percent of the stress that would cause failure in 10 years, the service life of the pipe could be extended to 50 years and for some materials to over 100 years. Manufacturers' data in support of such extrapolations need to be studied especially at the higher temperatures with new materials.

The design method does not account for the effect fittings and joints might have on the strength of the system nor does it adequately consider the cyclic type of loading known as water hammer which produces pressure surges above the prevailing hydrostatic line pressure.

In a building, the most severe pressure condition encountered by a thermoplastic-pipe water supply system appears to be that caused by a pressure surge above the normal line pressure in the hot water line (water hammer). In the modern residence, this condition is widely believed to occur during the operation of the automatic dishwasher with the peak pressure surge occurring when the hot water flow to the washer is suddenly stopped by the closure of an electric solenoid valve. This phenomenon can take place as many as six times during the cleaning of one load of dishes. If the washer is used three times a day, then in a 50-year service life the system might be expected to experience 325,000 pressure surges. A clothes washer might add to this number, but the surges produced by a clothes washer should be much less severe under normal opearating conditions. This severity is reduced as a result of the usual practice of using rubber hose in making the water supply connection to the clothes washer. Single handle and other types of "quick-closing" faucets tend to produce some degree of water hammer action but probably much less than does the dishwasher which is customarily "hard piped" to the hot-water distribution system.

Some characteristics values are shown in table 7 for the number of cycles to produce failure in CPVC from water hammer surge pressures. These values were reported by a manufacturer of CPVC pipe for a temperature of 180°F (82.2°C) Details of the test conditions were not given.

Table 7. Manufacturer's Test Data Showing for Five Levels of Water Surge Pressure, the Number of Water Hammer Surges Endured Prior to Failure of CPVC Pipe.

Surge Pressure psi	Cycles to Failure
400 (2.76 MPa)	1,000
300 (2.07 MPa)	2,000
200 (1.38 MPa)	5,000
100 (0.69 MPa)	32,000
50 (0.34 MPa)	Over 300,000

Since the surge pressure is the difference between the short-time peak pressure and the static pressure in the system during no flow, the data in table 7 indicates that if the maximum static pressure in the system is 100 psi (0.69 MPa), the peak cyclic pressure (static plus surge) which the system could withstand a large number of times without failure, is 150 psi (1.03 MPa).

The effects of water hammer may be controlled by means of a sealed air chamber or a field-fabricated pipe air chamber. The American National Standard for Water Hammer Arresters [17] states that the arresters shall limit, under the flow and pressure conditions specified in the standard test, the peak pressure (static plus surge) created by sudden valve closure to 150 (1.03 MPa) psi. Thus, it might be inferred that no water hammer arrester or air chamber would be required in generally accepted practice for a water distributing system as long as the peak pressure does not exceed 150 psi (1.03 MPa).

The review made in this study revealed little substantive data on the severity of water hammer in residences. A verbal communication with an official of the Association of Home Appliance Manufacturers, Inc., has indicated that the present trend in water supply solenoid valve usage in American-made home appliances is toward valves employing a controlled rate-of-closure mechanism. This type of solenoid valve should reduce the adverse effects of water hammer on the plumbing system. The review produced no data on the effects that the type and spacing of hangers or supports might have on the ability of a thermoplastic pressure-pipe water distribution system to withstand repetitive shock.

In summary, the structural design of a thermoplastic pressure-pipe system is based on applying a service factor to the long-term hydrostatic strength of the pipe. Service factors and long-term hydrostatic strengths developed from industry data have been published and are available for the design of this type of system [18, 19]. These service factors have been represented as accounting for the variability of manufacturing, test reliability, and the evaluation procedure as well as the effect of service temperature. They do not account directly for the effect of pressure surges on pipe life expectancy. Some information is available on the effect of water hammer in PVC pressure pipe but very little for CPVC pipe. Presently, plumbing authorities favorable to the controlled use of thermoplastics are of the opinion that the application of thermoplastic piping in domestic potable water distributing systems should be limited to a material with high resistance to the effects of hot water. CPVC is represented by the thermoplastic pipe manufacturing industry as such a material.

Recommendations for the type, spacing, and location of fixings or supports for both thermoplastic pressure distribution systems and thermoplastic drain-waste-vent systems, are given in industry literature. These recommendations are intended to assure that thermal expansion is provided for by design, and that sufficient rigidity of the system is provided to assure drainability and hydraulic capacity. Currently, code approvals are largely conditional on the requirement that the design and installation detail be strictly in accordance with industry recommendations. Many of these recommendations may be categorized as relating to structural parameters, e.g. restraint, expansion relief, fixings or supports, pressure limitations, etc.

3.5 Noise Control

3.5.1 Discussion of Sound and the Control of Noise

The field of acoustics is broad including many topics involving sound within the range of human hearing as well as, for example, sonar and ultrasonics. The discussion here will be limited to considerations of sounds that may be generated by the operations of plumbing systems in residential housing.

Sound can be created when any form of energy causes molecules or regions of solids, liquids or gases to vibrate with a higher level of activity than in their normal state. The sound energy resulting from such a transformation travels through the adjoining medium as a wave. The parameters of such wave motion (frequency, wavelength and amplitude) can often be identified through simple experiments. The square of the velocity of sound through the medium is proportional to the modulus of elasticity and inversely proportional to the density. But in general, the velocity of sound is greater through dense materials than through less dense materials [20, 21].

Sound is both physical energy and human sensory experience. When it reaches the ear of a person, sound may be either pleasant or unpleasant. Unwanted sounds are often called noise. The effect upon the hearer is more complex than can be considered here, and what is pleasant to one person may be very irritating to another. For example, many unpleasant sounds provide warning of danger and, therefore may be wanted sounds because of the message communicated. The very same sounds could be unwanted by persons having no interest in the danger message [22].

Happily, both wanted and unwanted sound may be controlled at its source, or at points along the path of transmission, or it may be controlled in the immediate vicinity of the hearer. Noise can be controlled in some cases by attention to the point of generation. Many times the unpleasant sounds can be identified as warnings of improper operation of a system. With the return to proper operation, the noise of the system may be reduced or eliminated. To protect the hearer from excessive noise, "acoustical materials" may be incorporated in the system to reflect or absorb some of the sound energy. Careful attention must be given to the paths of sound transmission called "leaks" and "flanking" paths. A tiny hole or a shrinkage crack in an acoustical wall panel can "leak" sound to reduce seriously the barrier effectiveness. Also the building structure may transport sound around a barrier to reach the hearer indirectly via a "flanking path" [23, 24].

3.5.2 Sound from a Piping System

Possible sources of sound in a plumbing system will now be considered. A fluid moving with steady low velocity (streamlined flow) does not create such sound. However, in most plumbing systems turbulent flow will develop, and as that flow increases more sound is generated. With turbulence, fluctuating flows, impact of air bubbles and other suspensions, and especially when flow separation or cavitation occur, some of the potential and kinetic energy of the flowing fluid is converted into sound, heat, and vibration. The flow in a full-pipe plumbing system can become turbulent from changes in direction and from occluded air. Lime deposits in water heaters and dissolved air in hot water can contribute to popping or hissing sounds upon heating or with sudden decreases in pressure. The shock waves which develop when a valve or faucet is suddenly closed cause the water hammer sound. Water passing through a faucet is usually turbulent because of the constriction of the water passageway through the valve seat and the resulting higher velocity at that place, and this can contribute to excessive noise. The impact of water on surfaces in a plumbing fixture creates sounds which depend on the geometry of the fixture, the direction of impact, and the material of the surfaces. Waste pipes and drainage stacks are almost never continuously full of flowing water, but flow instead with an intermittency conducive to noticeable sound generation. Turbulence in drainage flow may be characterized by trickling or rustling sounds. Other descriptive terms might be gurgling, plopping, roaring or sucking. Movement of the piping under hydraulic impact, thermal stress or structural shifting may also generate sound to be heard as a bump or knock; or if the clearances with the structure are not sufficient, creaking or cracking. Inadequate venting of trap and waste-pipe assemblies may result in gurgling or sucking sounds from the water seals in the fixture traps.

The paths for the transfer of sound from the piping system may be directly through the walls of the pipes to the air and to the listener, or indirectly through pipe supports or along the pipe to areas of contact with walls or structural elements and thence through the building materials to the air and the listener. Sound may be transmitted longitudinally inside pressure piping through the water. The control of sound from a plumbing system requires, at the design stage, an analysis of the possible sources and modes of energy conversion and of the paths for the transfer of sound; and during installation, the application of appropriate noise-control techniques.

3.5.3 Attenuation of Unwanted Sound

The continuous sound of moving fluids and the various aperiodic impulsive sounds provide stimuli to the auditory mechanisms of people. Whether such auditory sensations are acceptable, depends on the loudness, and on how the sensations intrudes on their activities. Even at low sound levels, a dripping faucet is annoying if one is trying to sleep and the house is quiet. The filling of a toilet tank or a bathtub, the flushing of a water closet, or the gurgling drainage of a bathtub can be bothersome if one is trying to listen to TV or phonograph or trying to use the telephone. Trickling sounds encourage enuresis (wetting) [25]. Trapped air in a water supply pipe can cause a bumping or popping sound when a faucet is opened, and sagging horizontal soil or waste pipes contribute to "pooling" that may produce dripping sounds.

The general approaches in design should be to control unwanted sounds at the source when feasible; or when this cannot be sufficiently accomplished, to place the partially controlled sound source as far as possible from sensitive activities. For example, a noisy waste system located in the walls of a dining room or living room may be rather objectionable for aesthetic reasons; therefore, the architect and plumbing designer should consider noise-control techniques such as enclosure with adequate acoustical material or an alternative location for the plumbing.

Pressure shock or hydraulic pressure surges can be reduced by using air chambers and by selecting valves and faucets that close slowly. In laundry and dishwashing machines the solenoid (electrically operated) valves should produce a suitable controlled rate of closure. Similarly, self-closing faucets should not close too quickly.

Clearances between pipe and structure must allow for the pipe movement in order to avoid impact on, or contact with, the adjacent structure. Such impact or contact of pipe and fittings with the studs, joists, or wall boards must be prevented if sound transmission is to be minimized.

Higher velocities of flow result in greater turbulence and noise levels. This is especially true where the flow undergoes a sharp change in direction or where the cross section is reduced. In drainage stacks, offsets may reduce sound intensity in some locations by reducing velocities, but the location of such offsets should be selected based on a consideration of the proximity to noise-sensitive human activity because offsets or bends in stacks tend to increase sound locally.

Between the piping and piping supports there should be placed a non-rigid material to reduce the vibratory coupling between pipe and structure. The supports should permit without excessive frictional restraint, the longitudinal pipe movement that results from thermal and hydraulic effects. Supporting hardware of various types is available that can accomplish these objectives.

Airborne sound passing from the piping system through walls, floors, and ceilings needs careful consideration. Sealing gaps and cracks in the enclosing structure with grouting, spackling, and non-drying caulking; and sealing pipe pentrations with caulking, or with close-fitting neoprene or fiber gaskets can appreciably reduce airborne sound. Heavy enclosing materials (e.g. masonary, thick gypsum board, or plaster walls) will attenuate the airborne transmission much more effectively than lighter material such as thin fiberglass-plastic sheet, thin gypsum board, or plywood paneling.

The overall objective in design of walls, chases, and floor-ceiling assemblies containing piping should be to obtain the same level of acoustical performance (acoustical transmission loss and acoustical radiation) as are acceptable for similar building elements without piping [26, 27].

In summary, it can be stated that unwanted sound (noise) in plumbing systems can orginate either in the water distributing system, in the plumbing fixtures and appliances, or in the drain-waste-vent system. Measures for minimizing this noise can be effectively taken at various stages, e.g. specification, design, installation, and maintenance. Until research produces more definite knowledge of the relative importance of different physical parameters and installation details in noise control, and produces advances in techniques for prediction of noise in a given design, the best practice is to apply existing knowledge at the appropriate stages in a building program, taking into account the general principles discussed here and in selected references [23, 24, 26, 27].

3.6 Hydraulic and Pneumatic Capacities

3.6.1 General

The design of a piping system is largely determined by the hydraulic requirements for the use of the system. Indeed, the characteristic critical phenomena occurring in the system are primarily derived from hydraulic action. Hydraulic system design involves considerations of the fluid dynamics, of the physical properties of the piping materials, and of the piping system structural characteristics. These considerations include the relationships between parameters such as the composition, pressure, and temperature of the fluid; the discharge rate and flow velocity; thermally or structurally induced movements; and the hydraulic functional durability of the system. If the design and installation of a piping system is not compatible with the properties of the materials specified, problems may be experienced through the mechanisms of the above-mentioned relationships. For example, effects induced through the mechanisms of thermal expansion/contraction or dimensional instability on exposure to intermittently hot and cold water, or through the mechanism of water hammer on sudden stopping of the flow of water in a pressure pipe can adversely affect performance capability in the important areas of acoustic acceptability, drainability, and leak/burst resistance.

3.6.2 Water Distribution Piping

All manufacturers of water distribution pipe and fittings seek to produce smooth interior surfaces in their products. The advantages of a smooth surface include low head loss; hence a potential for the use of a smaller size, a longer allowable length, or reduced energy requirements where pumping is involved. In addition, a smooth surface implies a potential for resistance to the accumulation of surface deposits. However, whether initial smoothness will be retained in service depends on whether the mechanisms of corrosion, deposition, or biological processes become predominant.

The Plastics Pipe Institute (PPI) has provided information on the selection of pipe sizes for thermoplastic pipes used in water distribution systems [28]. These aids to specification and design include formulas, tables, charts, and a nomograph. Brockman [29] reported no effect of hydrophobicity of the surface on flow properties in tests with polytetrafluoroethylene and brass tubes. Thus, it is reasonable to compute head loss as dependent on surface topography (hydraulic roughness), inside diameter of the pipe, flow velocity, and density and viscosity of the fluid.

The PPI recommendations are derived from the Hazen-Williams formula, as expressed in the following fashion:

$$H = 0.2083 \bullet \left(\frac{100}{C}\right)^{1.852} \bullet \frac{q^{1.852}}{d^{4.8655}}$$

where H = friction head in feet of water per 100 feet of pipe
d = inside diameter of the pipe in inches
q = flow rate in gallons per minute
C = constant for inside pipe roughness (a value of 150 is recommended for thermoplastic pipe)

Comparison has been made between this formula and the formula for "smooth" pipe, presented orginally by Hunter [30]. Hunter's formulas for pipes of several degrees of roughness were offered as practical approximations to the rational pipe flow formula described by Moody [31]. Hunter's formulas for "fairly smooth" and "fairly rough" pipe, (applied in a fashion described by Nielsen [32]) are the basis of current recommendations for thermoplastic pipe in the National Standard Plumbing Code (NSPC) [33] promulgated by the National Association of Plumbing-Heating-Cooling Contractors, Incorporated (NAPHCC) and the American Society of Plumbing Engineers (ASPE). In the comparison shown in table 8, computations were made for nominal diameters of 1/2, 1, and 2 inches at average flow velocities of 4, 6, and 8 feet per second. The average Hazen-Williams values at pressure gradients computed from Hunter's smooth-pipe formula over the stated range of velocity are 139 for 1/2-inch, 143 for 1-inch, and 147 for 2-inch pipe.

The NSPC recommends that where the water supply is "relatively non-scale forming," head losses should be computed from the "fairly-smooth" formula; that where "moderately scale forming," head losses should be computed from the "fairly rough" formula, and that where the water supply has an "appreciable scale-forming tendency and would otherwise result in clogging of small-diameter pipes and reduction of effective diameter of other piping in the system", the size selected for design should be one standard pipe size larger than would be obtained from the "fairly-smooth" formula. The PPI does not recommend an allowance for surface changes due to exposure to the water over a period of time. Thus, the question remains as to whether the chemical nature of the water supply has a significant effect on head loss in thermoplastic pressure pipe as the system ages in a typical service situation.

On the matter of water hammer as it affects the design and performance of water distributing systems in plumbing applications, the subject is discussed in Section 3.4 and 3.5.

In assessing the hydraulic aspects of water distribution piping, it is important to recognize the considerable effects of inside diameter on head loss and flow velocity for a given volume rate of discharge. Relatively small differences in actual diameters for a series of pipes of a given nominal diameter but conforming to different industry sizing standards can produce greater effects on pressure loss than variations in surface texture from smooth to fairly rough condition for pipes of a given actual diameter. This concept is illustrated in table 9 for several pipes conforming to different standards.

3.6.3 Drain-Waste-Vent Piping

As to hydraulic carrying capacities as affected by surface topography and actual diameter, the considerations for DWV piping are similar to those discussed for water-distributing piping in Section 3.6.2. Wyly and Eaton [34] have described the methodology upon which the carrying capacities of drainage and vent stacks is predicated and Wyly [35] has described methodology similarly for fixture branches and building drains, as evidenced in the loading tables of model plumbing codes such as BPC and NSPC. (See appendix, Section 8.1)

Another aspect of the hydraulic characteristics of initially smooth conduits such as copper, brass, thermoplastics, and stainless steel is that there is an appreciable potential for greater air demand by the drainage system, as can be demonstrated by calculation based on a formula for air demand rate given in NBS Monograph 31 [34]. This effect, however, may be largely counteracted by the greater air-carrying capacity of smooth vent piping.

Table 8. Computation of "C" in the Plastic Pipe Institute's "Hazen-Williams" Type Formula, For Head Losses Determined From Hunter's "Smooth Pipe" Equation For Selected Velocities And Diameters.

Nominal pipe size inches	Actual inside diameter D, inches	Actual inside diameter d, feet	Computed $\left(d^{.714}\right)$ 1/	Average velocity of water v, feet per second	Computed $\left(\frac{h}{100}\right)^{.571}$ 1/	Computed $\frac{h}{100}$	Computed h feet of head loss per 100 feet of pipe	Computed q cubic ft. per sec.	Computed Q gallons per min.	Computed $\left(\frac{h}{.2083}\right)^{.54}$ 2/	Computed $\left(D^{2.63}\right)$ 2/	Computed "Hazen-Williams" C 2/
0.5	.622	.0518333	.120846	8.0	.649019	.469034	46.9034	.0168810	7.57670	18.6362	.286859	141.7
0.5	.622	.0518333	.120846	6.0	.486764	.283398	28.3398	.0126607	5.68250	14.1972	.286859	139.5
0.5	.622	.0518333	.120846	4.0	.324509	.139317	13.9317	.0084405	3.78835	9.6754	.286859	136.6
1.0	1.049	.0874166	.175508	8.0	.446882	.243993	24.3993	.0480140	21.5501	13.0945	1.13407	145.1
1.0	1.049	.0874166	.175508	6.0	.335162	.147425	14.7425	.0360105	16.1626	9.9755	1.13407	142.9
1.0	1.049	.0874166	.175508	4.0	.223441	.072474	7.2474	.0240070	10.7751	6.7984	1.13407	139.8
2.0	2.067	.1722500	.284851	8.0	.275342	.104482	10.4482	.186422	83.6718	8.2831	6.75065	149.6
2.0	2.067	.1722500	.284851	6.0	.206506	.063130	6.3130	.139817	62.7541	6.3101	6.75065	147.3
2.0	2.067	.1722500	.284851	4.0	.137671	.031034	3.1034	.093211	41.8360	4.3003	6.75065	144.1

1/ Hunter's "Smooth Pipe" formula as shown on page 4 of BMS 79 (see reference 30 in section 6) may be written in the following form for a pipe length of 100 feet:

$$\left(\frac{h}{100}\right)^{.571} = \left(\frac{v}{102}\right) \cdot \left(d^{.714}\right)$$

2/ Plastic Pipe Institute thermoplastic pipe formula as shown on page 1 of PPI TR14, March 1971 may be written in the following form with D properly substituted for d and h for f :

$$C = \frac{100 \cdot Q}{\left(\frac{h}{.2083}\right)^{.54} \cdot \left(D^{2.63}\right)}$$

Table 9. Comparison of Average Velocities and Pressure Losses for 3/4" Nominal Size Pipe or Tube of Various Degrees of Roughness When the Volume Rate of Discharge is 10 Gallons Per Minute.

Computations / Piping Materials and Standards	Average Inside Diameter d, inches	Average Velocity V, ft/sec	Pressure Loss, pounds per square inch/100 feet of pipe			
			Smooth Condition	Fairly Smooth Condition	Fairly Rough Condition	Rough Condition
ABS or PVC, Schedule 40 ASTM D1527-73,D1785-73	0.824	6.02	8.66	10.70	13.15	19.23
ABS or PVC, Schedule 80 ASTM D1527-73,D1785-73	0.742	7.42	14.25	17.76	22.01	32.47
Copper, Type K ASTM B88-72	0.745	7.36	13.98	17.42	21.58	31.82
Copper, Type L ASTM B88-72	0.785	6.63	10.90	13.53	16.69	24.50
Copper, Type M ASTM B88-72	0.811	6.21	9.34	11.55	14.22	20.82
Copper Alloy 194, Standard ASTM B586-73	0.833	5.89	8.22	10.15	12.46	18.21
Copper Alloy 194, Heavy ASTM B586-73	0.815	6.15	9.12	11.28	13.88	20.32
CPVC SDR 11 ASTM D 2846-73	0.715	7.99	17.00	21.25	26.42	39.09
Galv. Steel, Schedule 40 ASTM A120-72a	0.824	6.02	8.66	10.70	13.15	19.23
Galv. Steel, Schedule 80 ASTM A120-72a	0.742	7.42	14.25	17.76	22.01	32.47
Stainless Steel, Grade G ASTM A651-71	0.837	5.83	8.04	9.92	12.17	17.78
Stainless Steel, Grade H ASTM A651-71	0.827	5.97	8.51	10.51	12.92	18.88

Note: Computations are based on four equations derived in BMS 79 (See Reference 20, Section 7).

Smooth pipe: $q = 4.93\, p^{0.571}\, d^{2.714}$ Fairly Smooth pipe: $q = 4.57\, p^{0.546}\, d^{2.64}$

Rough pipe: $q = 3.70\, p^{0.5}\, d^{2.5}$ Fairly Rough pipe: $q = 4.29\, p^{0.521}\, d^{2.562}$

where q = flow rate in gallons per minute, d = actual inside pipe diameter in inches, and p = pressure loss per 100 feet of pipe, in pounds per square inch. (Computations do not incorporate tolerances in computation of inside diameter).

The general problem in estimating hydraulic carrying capacities of drainage piping under service conditions is whether, and under what conditions and to what extent, carrying capacity is reduced due to effects of surface roughening and effective diamater reduction from deposition or build-up of surface coatings. This problem has not been studied in depth in the present review, but it appears that the problem is largely associated with nominally horizontal drains. It is believed that the relatively high velocities occurring in vertical drains tend to prevent significant build-up of surface deposits for all materials presently in widespread use. The degree to which initial surface smoothness is retained and to which such smoothness influences later hydraulic carrying capacity is dependent on numerous factors. In general, materials not subject to internal corrosion in the service environment would perform better in this respect than corrosion-prone materials. Under conditions where greasy wastes are involved or where other conditions exist that might contribute to the development of significant thicknesses of surface deposits in horizontal lines, it is believed that the effective service carrying capacity would be affected less by initial surface topography than it would be under the condition where only clean water is transported. This phenomenon, however, would not be expected for dry vent piping.

An important measure of performance in installed DWV systems, as well as in water distribution systems, is drainability. This attribute can be adversely affected by thermal expansion and permanent dimensional changes in the piping material. These properties should be taken into account in the stages of design and installation, particularly for thermoplastics and other temperature-sensitive materials, as discussed in Section 3.3 and 3.4.

3.7 Fire Safety

3.7.1 General

Two significant concerns have been identified arising from the use of thermoplastic piping for plumbing. These questions relate to life safety and are concerned with the potential for (a) fire spread and (b) spread of smoke and toxic gas in a buring building.

It is realized that ASTM D635-74 [37] provides a means for determining relative burning characteristics of plastic materials expressed in the terms "time of burning" and "extent of burning". The principal problem is that this test, while appropriate for comparing the relative burning characteristics of bar specimens under stated test conditions, does not provide for evaluation of the fire performance of the plumbing system, as affected by the many and varying parameters of construction introduced in building system design and installation. The ASTM Standard (D635-74) is not intended to be a criterion for fire hazard.

When thermoplastic pipe burns (a) it releases relatively large quantities of smoke and toxic gases, (b) it provides heat for increasing the intensity of the fire, (c) it may provide a path for flame spread along its surface, and (d) open holes may develop at wall or ceiling penetrations during the fire, which could provide a route for the passage of hot flame gases between rooms. These four characteristics must be considered when evaluating the fire risk associated with the use of thermoplastic pipe and pipe fittings in the water distribution and DWV systems in buildings.

Research has been directed toward the design of installations which would minimize the risks outlined above. The amount and kind of protection needed may depend on the air pressure difference between the room of fire origin and the room to which the fire could spread. This pressure difference could be as high as 0.1 inch of water (24.9 Pa) between rooms on adjacent floors and considerably higher than that between a burning room and the shaft in a high-rise building. Studies have been carried out by Tamura and McGuire at the National Research Council of Canada (NRCC) [36] on the pressure distribution in the shaft and in the rooms of high-rise buildings. The factors taken into account in calculating the pressure distribution include the "stack effect" (produced by the pressure differential that is caused by a difference between the interior and outside temperatures), the wind, air leakage through the walls and floors, and the presence of fire in any of the rooms. These pressures also control the movement of toxic gases and smoke.

One of the chief concerns in the use of plastic pipe is the toxicity of the products of pyrolysis and combustion. PVC yields mainly hydrogen chloride while ABS produces hydrogen cyanide, nitric oxide, and nitrogen dioxide in a fire environment. Table 10 [38] gives a general summary of the degree of hazard which can be expected from these gases along with carbon dioxide and carbon monoxide which will normally be present in the vicinity of a fire, even in the absence of plastics. The odor of HCl, even below endurance or eye irritation levels, can suggest a hazardous environment to people to the extent that they may be reluctant to egress via a moderately smoke filled area.

Table 10. Toxicity of Gases

Toxicity Considerations / Gases From Combustion	Concentration in parts per million			Symptoms at low concentrations
	To be fatal in 5-10 min. exposure	Dangerous to health in 1/2 - 1 hour exposure	Endurable for 1/2 to 1 hour exposure	
Carbon Monoxide	5,000	2,500	250	Tightness across forehead, slight headache
Carbon Dioxide	90,000	50,000	30,000	Shortness of breath, headache, unconsciousness
Hydrogen Chloride	3,000	1,000	500	Coughing or choking, irritation of eyes
Hydrogen Cyanide	200	100	50	Dizziness, confusion, weakness, headache
Nitrogen Oxides NO NO_2	500	100	50	Delayed pulmonary edema

In general, the undesirable effects of smoke are to reduce the visibility and thereby obscure the escape routes and also make it difficult for the firemen to locate the fire. Although it is unlikely that the smoke contributed by the thermoplastic pipe in a chase or wall cavity would be comparable to the smoke produced in the room of a fire origin, the smoke in a chase could find its way to other areas in a building.

The amount of thermoplastic pipe used in the plumbing system is usually small compared to the amount of thermoplastic material used in the furnishings of the building. Furthermore, the pipe is less likely to be ignited because of its location and function. However, because it comprises an integral part of a building service system important to health and safety, it is subject to regulations by the building and plumbing codes while the furnishings are usually exempt from such controls because they are not integral parts of the building.

3.7.2 Standard Fire Tests On Thermoplastic Piping

Small scale laboratory tests are sometimes used to measure fire related properties of building materials [39]. These properties include ease of ignition, flame propagation, heat release, smoke density, toxic combustion products, etc. For interior finish, the ASTM E84-70 tunnel test [40] is commonly used.

In the tunnel test the specimen is mounted on the ceiling of the chamber regardless of its orientation in use. In the case of plastics it is necessary to provide extensive support because of softening and melting. E84-70 provides the following guide for the mounting of plastics:

> "Thermoplastic materials and other plastics which will not remain in place are to be supported by 1/4-inch (6.3mm) round metal rods, or 3/16 x 2-inch (5 x 51mm) wide steel bars or 2-inch galvanized hexagonal wire-mesh supported with metal bars or rods spanning the width of the tunnel."

Thermoplastic PVC pipe was tested at the Southwest Research Institute (SWRI) [41] by splitting the full 25 feet of pipe longitudinally and supporting the two halves with the outer surface directed downwards and held in place with a wire mesh. Of four PVC pipes tested, three were rated with a flame spread of 10 and one with a flame spread of 20. A flame spread of 100 was reported for red oak flooring. While the results are apparently repeatable, they do not reflect the burning characteristics of thermoplastic materials as installed in a standard DWV plumbing system inside of a wall or chase. This is better accomplished in the fire endurance test (ASTM E119-73) [42] on the complete assembly.

In order to achieve a particular fire-endurance rating according to the test procedure of ASTM E119-73, a wall or floor-ceiling assembly must not permit the passage of flame or hot gases sufficient to ignite cotton waste, and the <u>temperature rise</u> at any point on the unexposed surface of the wall or assembly cannot be more than 325 °F (181 °C) during the fire-endurance period. This allowed temperature rise provides a margin of safety in anticipation of an additional rise due to the trapping of heat by combustible materials which could be in contact with the wall. When thermoplastic pipe penetrates the wall or ceiling, it <u>may</u> burn out and leave a hole for the passage of flame which <u>could</u> result in failure of the assembly. If the pipe is confined within the wall or ceiling the heat contributed by the burning pipe could cause an early failure of the assembly due to an excessive temperature rise on its unexposed surface.

However, by the use of a steel sleeve enclosing the plastic pipe where it penetrates the wall or ceiling and extending some distance on either side, the passage of flame can be prevented in some circumstances. Where the pipe passes into a plumbing chase enclosed on all sides by a fire-rated wall the possibilities for the passage of flame and the creation of excessive temperature rises on the surfaces of the interior walls of adjacent rooms due to the burning of the pipe can be greatly reduced.

Some research, described in Section 3.7.3, has been carried out to determine the installation details affecting fire performance in DWV systems by using protective metal sleeves or a chase, or both. No work of this nature has been reported for CPVC used for water supply piping.

According to laboratory tests the smoke density from the burning of PVC pipe is considerably higher than that from wood. The burning of PVC and CPVC liberates significant quantities of HCl, CO_2, and CO. There are no specific regulations on toxic gases, particularly from plastic pipe even though these properties are recognized as hazards caused by fire.

3.7.3 Fire Research On Thermoplastic Pipe Penetrations Through Walls

The spread of fire by the penetration of horizontal and vertical partitions by PVC and PE pipes was investigated at the Research Station in Studsvik, Sweden [43]. It was recommended that steel sleeves extending 20 inches on each side of the partition should be used for the horizontal penetration of PVC pipes of 4- and 6-inch diameters. For vertical penetrations, sleeves were recommended but the required length was not determined. It was stated that sleeves were not needed for either horizontal or vertical penetrations for 2-inch pipes of PVC or PE. The temperatures prevailing in the fire chamber were appreciably lower than for the time-temperature curve prescribed in the ASTM E119 fire endurance test, and no attempt was made to establish a definite positive pressure differential between the fire chamber and the unexposed region.

Some research was done in Holland on the fire hazard of pipes passing through a ceiling-floor assembly [44]. In one test a PVC pipe of 4.4-inch internal diameter was allowed to penetrate a 3.9-inch thick floor assembly. The pipe was extended 1 foot below the floor into the furnace and 2 feet into the ambient atmosphere above the floor. Flame appeared at the top of the pipe in 51 minutes. The important parameters in this research were pipe diameter and floor-assembly thickness. For a 2-inch inside-diameter pipe and a 2-inch floor the time for flame to appear at the top of the pipe was 72 minutes. It would appear that the effective ceiling thickness could be increased in practice with the use of noncombustible sleeves. The furnace pressure during these tests was 0.03 inches of water which is about one-third of the highest pressure differential which might be expected near the ceiling in a room fire. The results of the test might have been more severe if a higher furnace pressure had been used.

In the booklet, "Facts on Fire and PVC DWV" [45], a test is described where 4-inch PVC DWV pipe penetrated a fire wall which served as one side of the furnace. The pipe was enclosed in a .022-inch thick steel sleeve 2 feet long extending 10 inches on each side of the fire wall. The portion of the pipe extending past the external part of the sleeve was blanked off to represent a trap seal. The pressure in the furnace was not stated, but was controllable to permit selected pressure differentials to prevail. The furnace temperature was programmed to follow the ASTM E119 [42] time-temperature curve. A thermocouple located on the sleeve just outside the furnace indicated a 181 °C (325 °F) temperature rise in 65 minutes. The same temperature rise on the wall would constitute a one-point temperature failure in the ASTM E119 fire endurance test. The PVC pipe contained in the external sleeve and extending beyond it remained intact for the full 100 minutes that the test was run. However, it is believed that, if for any reason the seal at the unexposed end of the pipe had been broken so that the hot furnace gases could have passed through the pipe, more extensive damage would have occurred to the unexposed length of PVC pipe.

A study was conducted at the National Research Council of Canada (NRCC) [46] to investigate the influence of pipe penetration on the fire resistance of a partition. Pipes 2, 3, and 4 inches in diameter passed horizontally through a cylindrical chamber. The chamber temperature was programmed to follow the ASTM E119 time-temperature curve and the pressure rose to about 0.2 inch of water during the course of the run. The chamber was 16 inches in diameter and 39 inches long, terminated at each end with a concrete wall with an oversized hole where the pipe passed through. The opening around the pipe was filled in with soft asbestos. PVC, ABS, PE, PP, and fire-retardent PP pipes were tested. Each test involved a 10-foot length of pipe which extended 3 feet from each end of the furnace. One end of the pipe was sleeved as it passed through the test wall. The sleeve material was a .022-inch thick galvanized steel sheet which had been rolled to form a sleeve with an overlap of about 1 1/4 inch. The ends of the pipe were supported by wire and closed off with a metal cap and tape to represent a trap seal. A wall penetration was said to have failed when hot gases or flame issued freely around the pipe. The unsleeved ends of the PVC pipe failed in 45 to 55 minutes without regard to pipe size. The opening into the furnace at the unsleeved end was then closed off and the test was run for the remaining part of the 2 hours. The length of undestroyed pipe within the sleeve was measured at the end of the test.

The length of pipe destroyed beyond the wall of the chamber varied from 1/2 to 2 inches and did not seem to depend on the pipe diameter, which was varied from 2 to 4 inches, nor on the sleeve length which was varied from 4 to 9 inches. The sleeves reached temperatures of 600 °C (1112 °F) just beyond the end of the furnace and hence would be capable of igniting materials at that point. However, this characteristic could apply to metal as well as plastic pipes. In one test a 4-inch PVC pipe with a 9-inch sleeve on one side was tested with the ends of the pipe open to represent the case of a broken trap seal. Failure of the unsleeved end occurred at about 20 minutes, and the sleeved end at about 40 minutes. Preliminary experiments indicated that the observed effects might not be pressure dependent within the range of 0.05 to 0.5 inch of water.

Additional tests on the penetration of floor-ceiling assemblies were performed at NRC [47] where it was concluded that the performance during the first hour was unsatisfactory for all the pipes tested either because flame issued between the pipe and the sleeve which extended at least 9 inches above the floor or because a portion of the sleeve above the floor slab glowed red at some time.

3.7.4 Full Scale NBS Fire Tests On Thermoplastic Piping

ASTM E119 fire endurance tests were performed on wall and plumbing chases containing ABS, PVC, and metallic DWV systems at NBS [48, 49]. In each case there were back-to-back laterals connected to the stack through a double reducing sanitary tee. One lateral passed through the surface of the wall exposed to the test furnace while the other lateral penetrated the opposite wall surface. Both laterals (simulating sink drains) were terminated by water-filled traps as under normal service conditions. Thus a direct path was provided for the fire to progress through the wall or chase.

It was found that the fire endurance of a plumbing chase containing a 4-inch ABS stack with 3-inch ABS laterals was reduced to a value significantly less than the fire rating of the chase, whereas in a chase with a 4-inch PVC stack with 1 1/2-inch laterals the fire endurance was judged not significantly less than the chase rating. Tests showed that the situation with the ABS could be corrected by connecting the laterals to the stack by means of a wye so that they penetrated the chase wall at a downward angle of 45 degrees and were enclosed in steel sleeves extending downward from the point of penetration.

The endurance of a one-hour fire rated 2 x 4-wood-stud-and-gypsum-board wall was less than one hour with both ABS and PVC DWV systems using a 2-inch stack and 1 1/2-inch laterals. However, when the depth of the wall was increased by using 2 x 6 wood studs, both ABS and PVC systems passed the one-hour test successfully. But this success was contingent upon adequate sealing of the holes through which the laterals penetrated. It was also found very important that the lateral hubs of the stack-to-lateral junction fitting not penetrate through the surface of the wall.

3.7.5 Summary And Need For Future Fire Research

Concern continues to be expressed that somehow thermoplastic pipe and fittings in a building fire situation may contribute to the loss of life and property. Such fire hazard may be reduced to an acceptable level by the adoption of specific installation procedures, although such installation procedures may remove the economic benefits of plastic pipe in some cases. There are some obvious attractions in the use of thermoplastic piping, and its use has been increasing rapidly; but if its use in inappropriate installations could contribute significantly to fire hazards, its use may be banned by regulatory authorities in those applications.

In examining the nature of the small-scale tests (of penetrations of fire-walls by thermoplastic pipe) described earlier it is seen that they fall short of providing the assurance that the authors of the building codes would require. The penetrations in the tests reported have been limited to solid non-combustible partitions where the annular space around the pipe has been sealed off. This type of experimental arrangement does not represent typical field installations where the partition is typically hollow and may be of combustible construction, where the exposed side of the wall may be expected to collapse during the fire-rating period, and where the pipe penetrates through a hole that is larger than the pipe and may be only loosely sealed off with an escutcheon plate or not at all. Furthermore, these tests do not reflect the effect of the pipe on the fire endurance of the wall itself where the heat released by the burning pipe or by the furnace gases passing into the partition might either cause and early collapse of the fire-exposed wall or simply a higher temperature on the unexposed surface which may cause its maximum permitted temperature rise to be exceeded within the normal fire-rated period for the wall assembly.

The next step should be to subject typical plumbing installations, with both thermoplastic and metallic materials, to full scale fire tests in which the extent of the hazard created by each material would be measured. Then one is faced with the problem of <u>how</u> to measure the hazard. For example, we can measure the toxic gas and the smoke concentration in the cavity containing the pipe during a fire test, but the levels which would occur in an adjacent room will depend on the leakage through the cavity wall, particularly around the pipe where it penetrates the wall, on the dimensions of the room, and on the rate of ventilation. These effects would be expected to vary between field installations and would depend on the gas pressure differences.

The ASTM E119-73 fire endurance test for walls and floor-ceiling assemblies does not consider the special cases of either enclosed plumbing stacks or pipe penetrations. This raises the crucial question of how high in temperature should the pipe be permitted to rise at the point of penetration of the wall away from the fire. According to this test, at no point on the surface of the wall or floor-ceiling assembly away from the fire will the temperature as measured with a specified ASTM thermocouple be permitted to rise by more than 181 °C (325 °F). If we place the same requirement on the pipe then we might be restricting the use of metal pipes in applications in which they have been used for many years without any documented evidence of having contributed to fire spread! If the permissible limit of pipe temperature rise can be raised for metals, in all fairness the same must be done for the plastics. However, the limit should not be raised to the point that ignition of typical materials which might come in contact with the pipe could occur within the time period of the fire-rating time of the wall or floor-ceiling assembly. What this limit should be will require some further definitive research on the criterion for ignition in this situation.

A variety of additional plumbing installations need to be constructed, using both plastic and conventional materials, and tested in accordance with the standard E119-73 fire endurance test as described above. As before, the temperature rises of the pipes and the partition surfaces should be recorded along with the smoke and toxic gas concentrations detected on the unexposed sides.

As indicated above, improved measurement techniques and more analysis are needed, based on tests simulating typical plumbing installations. The results should help to establish guidelines for the safe use of thermoplastic piping in DWV systems and to establish realistic criteria for the acceptance of piping systems in general with respect to fire.

3.8 Compatibility With Drain-Cleaning Procedures

There is a need for clarification as to the appropriate methods to clean or remove obstructions from thermoplastic piping in plumbing systems. The question mostly relates to drainage piping, but to a lesser extent to vent piping also. Demonstrations have been made on ABS pipe which purport to show failures by penetration through the pipe fitting from the use of conventional rotoaugers [50]. Other demonstrations [51] have shown acceptable results. An alternative method to clear a drain is to introduce a mixture of powdered sodium hydroxide and aluminum. These chemicals, if introduced in sufficient quantity in the presence of water such as remains in a trap, react as an exothermic reaction which might heat the trap and adjoining pipe locally beyond the softening temperature, which could distort the trap, fitting, or pipe or even produce rupture. It needs to be established whether both methods are commonly used in the maintenance of thermoplastic DWV systems. With wider use of thermoplastics in these systems, it needs to be established whether in fact thermoplastics might be expected to be subject to frequent damage from these causes in a normal service environment in which occupants are generally unaware of such possible susceptibility of their plumbing systems and in which maintenance personnel are frequently inexperienced.

Traps may be either of metal or thermoplastics. If of thermoplastics, a greater risk of failure from cleaning procedures may exist but traps are not difficult to replace in most situations where access has been provided. With mechanical cleaning techniques care should be taken to select the least damaging type and size of rod, auger, or cutting head. Chemical cleaning is possible using substances which liquify or loosen grease and other fouling matter but do not heat excessively.

Drainage stacks and horizontal drains of thermoplastic pipe may be gently rodded or augered with tools having blunt circumferential and bend-negotiating features. Inspection at the cleanout openings can indicate the nature of the piping material (whether a thermoplastic or a metal), and this information should facilitate the selection of the appropriate cleaning technique and tools. Housings over the ends of scrapers and a clutch mechanism for the power-driven tool would assist in avoiding an over-stressing of the thermoplastic pipe. It is possible under some circumstances to clean drains with the carefully controlled use of compressed air or pressurized water.

If evidence should be produced showing a substantial problem in this area, then tests would need to be made on identical configurations of thermoplastic and metal piping utilizing selected, representative cleaning procedures. In such tests measurements should be made of the amounts of material removed, depth of scratching, loss of strength, change in dimensions, and development of leaks when the selected procedures are compared.

3.9 Weathering And Aging

The literature reviewed in this study did not describe tests for weathering resistance of pipe. Some tests of accelerated weathering of coupons made of the same material as the pipe were described in the BRAB reports [11, 52].

It is felt that the ASTM weathering tests and the BRAB weathering tests for plastics are not adequate for the case of plastic pipe with its particular configuration and internal stress situation. New tests and evaluative methods with a performance orientation are needed for evaluating this characteristic. Perhaps the most important question on weathering relates to the DWV application in which vents extend above the roof.

The aging properties of thermoplastic pipe do not appear to have been investigated experimentally. It is not too difficult to select or develop short-duration functional performance tests, and it is possible to develop accelerated tests in an effort to simulate the long-time effects of service conditions and the passage of time. However, neither method is sufficient to predict durability under their actual service conditions. In the first instance, quick functional performance tests do not incorporate any means for assessing degradation of physical properties due to the passage of time, and in the second instance highly accelerated tests may initiate untypical types of degradation.

None of the ASTM tests or the tests recommended by BRAB measure properties before and after aging. In the application of thermoplastics piping for plumbing, resistance to the forces developed by temperature changes, pressure shock, building settlement, timber shrinkage, etc., needs to be evaluated with reference to whether the properties essential to maintain functional performance (e.g., resistance to bursting or leaking, maintenance of drainability, etc.) are adequately maintained over long periods of exposure to typical environmental and service conditions.

4. AN APPROACH TO THE FORMULATION OF CRITERIA FOR THERMOPLASTIC PIPING AS USED IN RESIDENTIAL PLUMBING SYSTEMS

4.1 Fundamental Performance Requirements And Measures Of Performance

For a building component as thoroughly integrated into the building system as the piping used for a plumbing system, the essential functional characteristics include not only familiar characteristics such as leak resistance, drainability, and flow capacity, but also the more subjective and difficult-to-define characteristics of acoustical acceptability and fire safety.

The development of performance test methods that are meaningful requires first the conception of criteria that are related directly to user requirements, and then the establishment of a test method that simulates to an acceptable degree the chemical, mechanical, thermal, and structural environment to which the piping is exposed in actual use. This involves careful analysis of the important processes of user loads and of factors of degradation that are brought to bear on the piping system in service, and translation of these processes into the development of laboratory equipment that can be described definitively and reproduced, and that can measure the effects of these processes in quantitative terms. The broad objective is to identify suitable existing test methods wherever possible, and where there are no suitable existing tests to develop appropriate modification in the existing tests or to develop entirely new tests.

In the absence of comprehensive statistical data on use conditions generally, on the degradation of properties of materials in a service environment in particular, and on user expectations and tolerance levels, one practical approach to the establishment of performance levels is to select levels that either upgrade, downgrade, or maintain existing quality in the class of products in current use, based on the measured performance of a sampling of contemporary products. Decisions with respect to upgrading, downgrading, or maintaining present quality require the studied judgment of experienced persons acting together. Performance levels arrived at in this way would, of course, be subject to later adjustment as more extensive service data and user reaction become available. The alternative, beginning with the collection of comprehensive data on service conditions, installation detail, user response, etc. could be prohibited in cost.

The principal user requirements for the piping as installed in plumbing systems can be classified in three categories: (a) hydraulic functional adequacy, (b) adequacy for health and safety, and (c) adequacy for durability/maintainability.

Functional performance is determined mostly by the following attributes:

(a) Resistance to leakage or bursting from service static pressure differentials, internal pressure shock, etc.

(b) The provision of adequate drainability of nominally horizontal pipes subjected to normal live and dead loads, and to a normal thermal environment.

(c) The provision of adequate hydraulic/pneumatic carrying capacity of the piping system subjected to normal thermal and hydraulic exposure.

(d) The provision of acoustical acceptability under normal operating conditions, taking into account noise reduction between living units through interdwelling walls or floor-ceilings, and noise reduction between spaces within a living unit through walls and partitions.

Performance with respect to the requirements of health and safety is determined largely by toxicological acceptability (non-transfer of hazardous materials to potable water), and by fire safety factors (the spread of fire, smoke and toxic gases in building fires).

Durability and maintainability performance is determined by the combination of physical properties, installation detail, and service environment as they might be related to degradation of functional performance of a piping system. Among the principal measures are:

(a) Resistance to the normal chemical environment that might tend to produce chemical attack, particularly attack of the type that would lead to environmental stress cracking under typical structural load patterns.

(b) The effects of repetitive thermal and structural loads, and of weathering and aging on the stability of critical dimensions, and on the maintenance of leak resistance of the piping over an extended period of service.

(c) Resistance to abrasion from pipe hangers, guides, and supports; and from typical contents transported in a nominal service environment.

From the foregoing discussion, it can be seen that criteria for piping in the context of performance involves pipe, fittings, and the structural interface in a number of instances. A definitive knowledge of the particulars of the service environment is needed to develop performance criteria.

4.2 Some Shortcomings Of Existing Methods Of Evaluation

The existing methodology is characterized by two shortcomings, insofar as the performance approach is concerned: (1) the standards are mostly developed for pipes, tubes and fittings separately, rather than as an assembly (although a recent trend to "system" standards has been noted), and (2) the standards tend to measure physical properties as related primarily to the maintenance of uniform quality in production and to identification of the product rather than to the means for predicting service performance of installed systems through performance tests.

4.3 The Current Need

A framework is first needed to provide guidance both in the practical application of relevant portions of the existing evaluation methodology from a performance standpoint, and in the definition of areas of need in test development and research. Although the present program is limited mostly to considerations believed most relevant to thermoplastics, the approach might be applicable, with some expansion, to the determination of adequacy of performance for other piping materials. A framework for criteria developed in this way has been described in some detail in another report on the current program [53]. It is anticipated that further work will provide significant input of the type required to render this approach useful and adequate for the evaluation of new materials or of familiar materials in essentially new applications. The alternative is the traditional approach that requires a relatively long period of trial and error together with the gradual accumulation of satisfactory service history from trial installations as the basis for general acceptance.

5. CONCLUSIONS

5.1 General Statements

The pattern of plastic pipe use is rapidly changing. At present three materials dominate the plastic plumbing materials market for above-ground residential use. These are ABS (acrylonitrile-butadiene-styrene), PVC poly(vinyl chloride), and CPVC (chlorinated PVC). The first two materials have enlarged and increasing usage for drain-waste-vent applications, and the latter is currently being used increasingly for hot and cold water distributing piping. Other plastic piping materials such as PB (polybutylene) and PP (polypropylene) are being used in some applications and may be seriously considered for residential plumbing when and if the economic factors become favorable.

The principal issues with respect to the use of thermoplastics piping for residential above-ground plumbing in recent years have related to:

1. Potential fire hazards.

2. Effects of intermittent or continuous exposure to hot water.

3. Potential for chemically induced cracking (environmental stress cracking).

4. Effects of continuous hydrostatic pressure and intermittent water hammer.

5. Adequacy of acoustical performance.

6. Capability to assure adequacy of critical design and installation details through routine inspection procedures.

Regulatory agencies that have approved the use of thermoplastics piping for plumbing have in many instances imposed limitations, e.g., height, location, type of waste, type of occupancy, fire rating of building, pipe wall thickness, special installation rules, arbitrary test requirements, etc.

5.2 Potential For Satisfactory Performance Of Thermoplastics Piping In One- And Two-Story Residences

With reference to above-ground applications of NSF-listed ABS and PVC for drain-waste-vent piping and of NSF-listed CPVC for hot and cold water piping in one- and two-story residences, it appears that performance is dependent to a significant degree on details of design, installation and inspection. A coordinated program to identify these details and to publicize them among designers, installers, and inspectors is needed, and some laboratory experimentation is needed under simulated service conditions to examine important performance aspects of the thermoplastics not specifically addressed in current standards.

5.3 Potential For A Broad Application Of The Performance Approach

Considering potentially broader applications of the familiar materials and the potential introduction of new materials, it is evident that adequate measures of performance under simulated end-use conditions do not exist for several significant characteristics: e.g., functional, durability, or safety performance characteristics related to creep, thermally induced stress relaxation, leak resistance of joints, emission of smoke and toxic gases. For this reason, it is important that a broad performance-type framework be developed for evaluation purposes, that would be applicable of a contemporary material. This concept was adopted in the formulation of the test program recommended in Section 5.4, with an emphasis on thermoplastics in above-ground residential plumbing.

5.4 A Recommended Laboratory Program

This review of current practice in the application of thermoplastic pipe in plumbing systems provided the basis for the experiments recommended for developing performance criteria for piping material and subassemblies in residential plumbing under HUD sponsorship. These experiments can be briefly described as follows:

(1) Hot-water test: thermal cycling in DWV and pressure piping assemblies representing as-installed configurations, taking into account different methods of support, attachment to structure, restraint methods, etc. Observations to be made for evidence of leakage, deflection, sag, creep, abrasion against supports, axial forces, change in cross section, etc.

(2) Thermal properties tests: bench tests to evaluate significant physical properties or changes in properties of small specimens of pipe and fittings as a function of thermal environment; e.g., creep, hardness, ultraviolet radiation effects, internal stress effects, etc.

(3) Water hammer tests: tests on assemblies of pipe and fittings to study resistance to bursting (leaking) as affected by pressure magnitude, number of pressure cycles, temperature, technique of making and curing joints, etc.

(4) Fire tests on DWV systems installed in walls and chases, taking into account appropriate measures of performance and studying the effects of size of stacks and penetrations, of type of piping material, of detail of wall or chase construction, and of DWV system configuration.

The results of the tests indicated in (1) through (4) above are being presented in other reports on the current program. Results of fire tests on selected constructions and on procedures for thermal performance characteristics have been reported [49, 54]. Other reports are in review [53, 55, 56].

ACKNOWLEDGMENT

The authors acknowledge important contributions made by the following persons: E. Thomas Pierce, Physicist, National Bureau of Standards, Center for Building Technology, developed the material used in the noise control section. John F. Halldane, Environmental Systems Consultant, prepared the initial emendation which serves as the framework of this completed report. William J. Werner, General Engineer, Office of Policy Development and Research, Department of Housing and Urban Development, made many valuable suggestions during the planning stages of the project and during the review process. Frank W. Reinhart, Technical Director, Plastics Pipe Institute supplied up-to-the-minute compilation of applicable technical data. Samuel D. Toner, Chemist, Product Engineering Division, National Bureau of Standards, Institute for Applied Technology, provided painstaking, critical review and contributed valuable recommendations.

6. REFERENCES

[1] Hoffer, William "The Great American Dream House, Its Woes and Its Future," Washington Post/Potomac, April 22, 1973.

[2] Wyly, R. S. and Rorrer, D. E. "Field Test of Hydraulic Performance of a Single-Stack Drainage System at the Operation BREAKTHROUGH Prototype Site in King County, Washington," National Bureau of Standards (U.S.) NBSIR 73-161, 58 pages, May 1973.

[3] McJunkin, F. E. and Pinco, C. S. "The Role of Plastic Pipe in Community Water Supplies in Developing Countries," Department of Environment Science and Engineering, University of North Carolina to Agency for International Development, Contract AID/csd-1888 Task Order No. 3, 1969, U.S. Governemnt Printing Office, Stock No. 4401-0033.

[4] D/E Journal, "1974 Report, Trends in Codes and Standards," Vol. 223, No. 3., March 1974.

[5] D/E Journal, "Trends in Codes and Standards 1973," Vol. 221, No. 3, March 1973.

[6] World Health Organization, "International Standards for Drinking Water," Geneva, 2nd Edition, 1963.

[7] U.S. Public Health Service, "Drinking Water Standards, 1962," U.S.P.H.S. Pub. No. 956, U.S. Public Health Service, U.S. Government Printing Office, Washington, D.C., 1962.

[8] "A Study of Plastic Pipe for Potable Water Supplies," Directed by W. D. Tiedeman and N. A. Milone, National Science Foundation, Ann Arbor, Michigan, June 1955.

[9] Korshak, V. V. "The Chemical Structure and Thermal Characteristics of Polymers," Translated from Russian by J. Schmorak, Israel Program for Scientific Translations, Jerusalem, 1971.

[10] ASTM D 674-56 (Reapproved 1969) "Standard Recommended Practices for Testing Long-Time Creep and Stress-Relaxation of Plastics Under Tension or Compression Loads at Various Temperatures," American Society for Testing and Materials, Philadelphia, Pennsylvania, 1974.

[11] Task Group T-52, "Thermoplastic Piping for Potable Water Distribution Systems," Federal Council Technical Report No. 61, Building Research Advisory Board - National Research Council, National Academy of Sciences, Washington, D.C., 1971.

[12] ASTM D 2846-73, "Standard Specification for Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Hot Water Distribution Systems," American Society for Testing and Materials, Phildelphia, Pennsylvania, 1974.

[13] "Recommendations and Installation Procedures for Genova Rigid-Vinyl Pipe and Fittings," Booklet No. 001, Genova Products, 300 Rising Street, Davison, Michigan, 48423.

[14] ASTM D 2665-74, "Standard Specification for Poly(Vinyl Chloride) (PVC) Plastic Drain, Waste and Vent Pipe and Fittings," American Society for Testing and Materials, Philadelphia, Pennsylvania, 1974.

[15] ASTM D 2661-74, "Standard Specification for Acrylontrile-Butadiene-Styrene (ABS) Plastic Drain, Waste, and Vent Pipe and Fittings," American Society for Testing and Materials, Philadelphia, PA, 1974.

[16] "Thermoplastic Water Piping Systems," Technical Report PPI-TR16, August 1973, Plastics Pipe Institute, New York, New York.

[17] ANSI A112.26.1 - 1969, "Water Hammer Arresters," American National Standards Institute, Incorporated, New York, New York.

[18] "Recommended Hydrostatic Strength and Design Stresses for Thermoplastic Pipe and Fitting Compounds," Technical Report PPI-TR4, March 1974, Plastics Pipe Institute, New York, New York.

[19] "Recommended Service (design) Factors for Pressure Applications of Thermoplastic Pipe Materials," Technical Report PPI TR9, August 1973, Plastics Pipe Institute, New York, New York.

[20] Beranek, L. L., editor, Noise and Vibration Control, (McGraw-Hill, New York, 1971).

[21] Kinsler, L. E.; Frey, A. R., Fundamentals of Acoustics, (John Wiley and Sons, New York, 1962).

[22] Kryter, K. D., The Effects of Noise on Man, (Academic Press, New York, 1970).

[23] Peterson, A. P. G.; Gross, E. E., Handbook of Noise Measurement, (General Radio Company, Concord, Massachusetts, 1972).

[24] Yerges, L. F., Sound, Noise, and Vibration Control, (Van Nostrand Reinhold, New York, 1969).

[25] Halldane, J. F.: Khosla, N. K., "Sound Measurement," prepared by Enviro-Management and Research, Incorporated, Washington, D.C. for National Institue for Occupational Safety and Health, Contract HSM-99-72-60, November 1972.

[26] Berendt, R. D.: Winzer, G. E.: Burrough, C. B. "A Guide to Airborne Impact, and Structure Borne Noise-Control in Multifamily Dwellings," HUD FT/TS - 24, U.S. Department of Housing and Urban Development, Washington, D.C., 1967.

[27] Egan, M. D., Concepts in Architectural Acoustics, (McGraw-Hill, New York, 1972).

[28] "Water Flow Characteristics of Thermoplastic Pipe," Plastics Pipe Institute, Technical Report PPI-TR14, March 1971, Plastics Pipe Institute, New York, New York.

[29] Brockman, Marion R., "Resistance of Flow in Teflon and Brass Tubes," J. Res., National Bureau of Standards (U.S.) 58, No. 1 RP 2734, 51-60, January, 1957.

[30] Hunter, Roy B., "Water Distributing Systems for Buildings," National Bureau of Standards (U.S.) Building Materials and Structures Report, BMS 79, 1-25, November 1941.

[31] L. F. Moody, "Friction Factors for Pipe Flows," Trans. Am. Soc. Mech. Engrs., Volume 66, 671 (1944).

[32] Nielsen, L. S., "Accurate Pipe Friction Charts and How to Apply Them," Plumbing-Heating-Cooling Business, Series of 7 Articles, April 1967 through October 1967.

[33] "National Standard Plumbing Code," PHCC-ASPE National Association of Plumbing-Heating-Cooling Contractors, June 1973.

[34] Wyly, R. S.: Eaton, H. N., "Capacities of Stacks in Sanitary Drainage Systems for Buildings," National Bureau of Standards (U.S.) Monogr. 31, 52 pages, June 1965.

[35] Wyly, R. S., "Investigation of the Hydraulics of Horizontal Drains in Plumbing Systems," National Bureau of Standards (U.S.) Monogr. 86, 38 pages, December 1964.

[36] McGuire, J. H. and Tamura, G. T., "Smoke Control in High Rise Buildings," Canadian Building Digest, CBD 134, January 1971.

[37] ASTM D635-74, "Standard Method of Test for Flammability of Self-Supporting Plastics," American Society for Testing and Materials, Philadelphia, Pennsylvania, 1974.

[38] Hilado, C. J., Flammability Handbook for Plastics, (Technomic Publishing Company, Stamford, Connecticut, 1969), LC-Card 68-56415, 164 pages, paperbound.

[39] "Standard Types of Building Construction," NFPA No. 220 - 1961, National Fire Protection Association, Boston, Massachusetts.

[40] ASTM E84-70E, "Standard Method of Test for Surface Burning Characteristics of Building Materials," American Society for Testing and Materials, Philadelphia, Pennsylvania, 1974.

[41] Armstrong, G. W., "Investigation of Surface Burning Characteristics of Four Polyvinylchloride Pipes (Formulations: GEON 85611, 85617, 85092, and 8761), Project Report 312446 - 132, Southwest Research Institute, San Antonio, Texas, June 1969.

[42] ASTM E119-73E, "Standard Methods of Fire Tests of Building Construction and Materials," American Society for Testing and Materials, Philadelphia, Pennsylvania, 1974.

[43] "Fire Tests with Plastic Tubes Carried Out at the Research Station in Studsvik, Spring 1963," Report 18: 1966 National Swedish Institute for Building Research, Stockholm, Sweden.

[44] Van Sante, F. J., "Results of Fire Tests on Plastic Pipes and Sheets for Covering Walls and Ceilings," Foundation Ratiobouw, Holland, 1968.

[45] "Facts on Fire and PVC DWV For Fire Rated Construction," Genova Technical Report No. 1, Genova Products, Incorporated, Davison, Michigan, 1970.

[46] McGuire, J. H.; Huot, P., "Fire Tests Concerning the Penetration of Walls by Horizontal DWV Pipes," National Research Council of Canada, Technical Note 577, January 1971.

[47] McGuire, J. H., "Penetration of Fire Partitions by Plastic DWV Pipe," Fire Technology, Volume 9, No. 1, February 1973, pp. 5-14.

[48] Benjamin, I. A.; Parker, W. J., "Fire Spread Potential of ABS Plastic Plumbing," Fire Technology, Volume 8, No. 2, May 1972, pp. 104-119.

[49] Parker, W. J., "Fire Endurance Tests on Walls and Plumbing Chases Containing Either Metallic or Nonmetallic Drain Waste and Vent Systems," National Bureau of Standards (U.S.) NBSIR 74-449, November 1973.

[50] Pearson, H. M., "Durability Tests, 3" ABS Pipe Assemblies," Engineers Testing Laboratories, Incorporated, Phoenix, Arizona, 1966.

[51] Dauphin, Ed., "Lafayette, Louisiana Test ABS-DWV for Lafayette Plumbing Board, Mr. C. C. Hargis, Chairman," Southern Building Magazine, Birmingham, Alabama, August 1968.

[52] Task Group T-52, "Rigid Thermoplastic Pipe and Fittings for Residential Drain - Waste and Vent Systems," Federal Council Technical Report No. 52, Building Research Advisory Board - National Research Council, National Academy of Sciences, Washington, D.C., 1966.

[53] Wyly, R. S.; Beausoliel, R. W.; Parker, W. J.; Pierce, T.; Rorrer, D. E.; Shaver, J.; Sherlin, G. C.; Tryon, M., "Interim Report on Criteria for Thermoplastic Piping Materials for Above-Ground Use in Water Supply and Drainage for Residential Buildings," National Bureau of Standards (U.S.) NBSIR (in review).

[54] Tryon, M., "Investigation of Procedures for Determination of Thermal Performance Characteristics of Plastic Piping Used in Housing," National Bureau of Standards (U.S.) NBSIR 74-610, November 1974.

[55] Scott, J. T.; Parker, W. J.; Paabo, M., "Fire Endurance of Gypsum Board Walls and Chases Containing Plastic and Metallic Drain Waste and Vent Systems," National Bureau of Standards (U.S.) BSS (in review).

[56] Tryon, M., "Thermal Properties of Selected Plastic Piping Used in Housing," National Bureau of Standards (U.S.) NBSIR 74-629.

7. DEFINITIONS AND NOMENCLATURE

ABS: Acrylontrile-butadiene-styrene, a thermoplastic material used in drain, waste and vent piping systems and also for shallow-well water piping and for gas distribution. The minimum content of each component is: acrylontrile, 13 percent; butadiene, 5 percent; and styrene and/or substituted styrene, 15 percent.

Administrative Authority: The individual official, board, department, or agency established and authorized by a state, county, city or other political subdivision created by law to administer and enforce the provisions of the plumbing code as adopted or amended. (NSPC)

Aging: The effect on materials of exposure to an environment for an interval of time; also, the process of exposing materials to an environment for an interval of time. (ASTM)

Backflow: The flow of water or other liquids, mixtures, or substances into the distributing pipes of a potable supply of water, from any source or sources other than its intended source. Back-siphonage is one type of backflow. (NSPC)

Chase: In plumbing usage, a shaft constructed specifically to enclose the plumbing piping in a fire-resistant construction.

Code: As related to plumbing work, usually an ordinance, with any subsequent amendment thereto, or any emergency rules or regulations which a city or a governing body may adopt to control the plumbing work within its jurisdiction.

CPVC: Chlorinated poly(vinyl chloride), a thermoplastic material used for piping in hot and cold water distribution systems.

DWV Systems: The drain-waste-vent system, includes all the sanitary drainage and vent piping inside the building or relevant portion thereof, and includes the building drain to its point of connection with the building sewer.

Extrusion: A process whereby heated or unheated plastic forced through a shaping orifice becomes one continuously formed piece. (ASTM)

Fitting: A device used to join or to terminate sections of pipe.

Horizontal Branch: A horizontal branch is a drain pipe extending laterally from a soil or waste stack or building drain with or without vertical sections or branches, which receives the discharge from one or more fixture drains and conducts it to the soil or waste stack or to the building drain.

Lateral: A word that has appeared in recent reports on fire tests of plastic plumbing systems. It is synonymous with "fixture drain", "trap arm" or "horizontal branch".

Molding, Compression: A method of forming objects from plastics by placing the material in a confining mold cavity and applying pressure and usually heat. (PPI)

Molding, Injection: A method of forming plastic objects from granular or powdered plastics by the fusing of plastic in a chamber with heat and then forcing part of the mass into a cooler chamber where it solidifies. (PPI)

Pipe: The term is applied generally to tubular products and materials commonly used to conduct or transport fluids or gases. In this specific nomenclature, "pipe" usually has greater wall thickness than similar products called "tube" or "tubing".

Piping: This term has a broader meaning than the term "pipe". For example, "cold water piping" includes the pipe, tube, or tubing used to conduct the cold water; the fittings used to change the direction of flow or change the size of pipe, tube, or tubing; and the valves used to control or regulate the rate of flow and the direction of flow. "Hot water piping" and "drainage piping" have similarly broad meanings.

Plastic Pipe: A hollow cylinder of a plastic material in which the wall thickness are usually small when compared to the diameter and in which the inside and outside walls are essentially concentric. See plastic tubing. (ASTM)

Plastic Tubing: A particular size of plastic pipe in which the outside diameter is essentially the same as that of copper tubing. See plastic pipe. (ASTM)

Polybutylene Plastics: Plastics based on polymers made with butene as essentially the sole monomer. (ASTM)

Polyethylene: A polymer prepared by the polymerization of ethylene as the sole monomer. See polyethylene plastics. (ASTM)

Polyethylene Plastics: Plastics based on polymers made with ethylene as essentially the sole monomer. Note: In common usage for these plastics, essentially means no less than 85% ethylene and no less than 95% total olefins. (ASTM)

Polymer: A compound formed by the reaction of simple molecules having functional groups that permit their combination to proceed to high molecular weights under suitable conditions. Polymers may be formed by polyaddition (addition polymer) or polycondensation (condensation polymer). When two or more monomers are involved, the product is called a copolymer.

Polymerization: A chemical reaction in which the molecules of a monomer are linked together to form large molecules whose molecular weight is a multiple of that of the original substance. When two or more monomers are involved, the process is called copolymerization or heteropolymerization. (PPI)

Polypropylene: A polymer prepared by the polymerization of propylene as the sole monomer. See polypropylene plastics and propylene plastics. (ASTM)

Polypropylene Plastics: Plastics based on polymers made with propylene as essentially the sole monomer. (ASTM)

Poly(vinyl chloride): A resin prepared by the polymerization of vinyl chloride with or without the addition of small amounts of other monomers. (PPI)

Poly(vinyl chloride) Plastics: Plastics made by combining poly(vinyl chloride) with colorants, fillers, plasticizers, stabilizers, lubricants, other polymers, and other compounding ingredients. Not all of these modifiers are used in pipe compounds. (PPI)

Potable Water: Water free from impurities present in amounts sufficient to cause disease or harmful physiological effects and conforming in its bacteriological and chemical quality to the requirements of the Public Health Service Drinking Water Standards or the regulations of the public health authority having jurisdiction. (NSPC)

Pressure: When expressed with reference to pipe, the force per unit area exerted by the fluid in the pipe.

Propylene Plastics: Plastics based on resins made by the polymerization of propylene or copolymerization of propylene with one or more other unsaturated compounds, the propylene being in greatest amount by weight. (PPI)

Self-Siphonage: Reduction in trap seal of a fixture after completion of the fixture discharge, caused solely by the discharge of that fixture.

Stack: The vertical main of a system of soil, waste or vent piping.

Thermoplastic (noun): A plastic which is thermoplastic in behavior. (PPI)

Thermoplastic (adjective): Capable of being repeatedly softened by increase of temperature and hardened by decrease of temperature. Note: Thermoplastic applies to those materials whose change upon heating is substantially physical. (PPI)

Thermoset (noun): A plastic which, when cured by application of heat or chemical means, changes into a substantially infusible and insoluble product. (PPI)

Thermoset (adjective): Pertaining to the state of a resin in which it is relative infusible. (PPI)

Thermosetting: Capable of being changed into a substantially infusible or insoluble product when cured by application of heat or chemical means. (PPI)

Trap: A fitting or device constructed in a drain so as to provide, when properly vented, a water seal for protection against the emission of noxious or explosive sewer gases, without significantly retarding the flow of sewage or waste water through it.

Trap Arm: Another name for fixture drain.

Vent: A pipe installed to provide a flow of air to or from a drainage system or element thereof so as to provide protection of trap seals from siphonage and back pressure.

Vinyl Chloride Plastics: Plastics based on resins made by the polymerization of vinyl chloride or copolymerization of vinyl chloride with other unsaturated compounds, the vinyl chloride being in greatest amount by weight. (PPI)

Water Distribution (distributing) Pipe: A pipe within the building or on the premises which conveys water from the water-service pipe to the point of usage. (NSPC)

Water Hammer: The term used to identify the hammering noises and severe shocks that may occur in a pressurized water supply system when flow is halted abruptly by the rapid closure of a valve or faucet.

Water Outlet: A discharge opening through which water is supplied to a fixture, into the atmosphere (except into an open tank which is part of the water supply system), to a boiler or heating system, or to any devices or equipment requiring water to operate but which are not part of the plumbing system. (NSPC)

Water Service Pipe: The pipe from the water main or other source of potable water supply to the water distributing system of the building served. (NSPC)

Note: Definitions found in this section are intended to be identical with those identified by the abbreviations (ASTM), (NSPC), and (PPI). For those definitions listed but not identified by one of the abbreviations, some modifications have been made to definitions which may have been found elsewhere in the technical literature.

(ASTM) - ASTM D 883-73a
(NSPC) - National Standard Plumbing Code 1973
(PPI) - PPI-TRI-November 1968

8. APPENDIX

8.1 Model Codes

Basic Plumbing Code (BPC)

Building Officials and Code Administrators International, Inc. (BOCA)
1313 East 60 Street, Chicago, Illinois 60637

National Standard Plumbing Code (NSPC)

American Society of Plumbing Engineers (ASPE) and National Association of Plumbing-Heating-Cooling Contractors (NAPHCC)
1016 20th Street, N.W., Washington, D.C. 20036

Southern Standard Plumbing Code (SSPC)

Southern Building Code Congress (SBCC)
3617 8th Avenue, South, Birmingham, Alabama 35222

Uniform Plumbing Code (UPC)

International Association of Plumbing and Mechanical Officials (IAPMO)
5032 Alhambra Avenue, Los Angeles, California 90032

Canadian Plumbing Code (CPC)

Associate Committee on the National Building Code
National Research Council of Canada
Ottawa, Ontario, Canada, K1AOR6

8.2 Specifications and Standards

This section contains a list of widely-referenced plastics piping standards including standards for materials, methods of test, and recommended practices for the design and installation of pipe, fittings and related products made of plastics. Those standards marked with an asterisk contain information on engineering design criteria and/or the closely related installation procedures.

8.2.1 ASTM

American Society for Testing and Materials
1916 Race Street
Philadelphia, Pennsylvania 19103

For the purposes of this report, the ASTM Standards are divided into groups as follows:

8.2.1.1 Specifications for Plastics Pipe, Fittings, and Related Materials

A) Acrylonitrile-Butadiene-Styrene (ABS)

D1527-73a Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe, Schedules 40 and 80. (ANSI B72.5 - 1971)

D1788-73 Rigid Acrylonitrile-Butadiene-Styrene (ABS) Plastics. (ANSI K65.205 - 1971)

D2282-73a Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe (SDR-PR). (ANSI B72.3 - 1967)

D2465-73 Threaded Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe Fittings, Schedule 80. (ANSI K65.165 - 1971)

D2468-73 Socket-Type Acrylonitrile -Butadiene-Styrene (ABS) Plastic Pipe Fittings, Schedule 40. (ANSI K65.164 - 1971)

D2469-73 Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe Fittings, Schedule 80. (ANSI K65.163 - 1971)

D2661-74 *Acrylonitrile-Butadiene-Styrene (ABS) Plastic Drain, Waste, and Vent Pipe and Fittings. (ANSI B72.18 - 1971)

D2680-74 Acrylonitrile-Butadiene-Styrene (ABS) Composite Sewer Piping.

D2751-73 Acrylonitrile-Butadiene-Styrene (ABS) Sewer Pipe and Fittings. (ANSI K65.59 - 1971)

B) Poly(vinyl chloride) (PVC)

D1784-69 Poly(vinyl chloride) (PVC) Compounds and Chlorinated Poly(vinyl chloride) (CPVC) Compounds, Rigid. (ANSI K65.206 - 1971)

D1785-74 Poly(vinyl chloride) (PVC) Plastic Pipe, Schedule 40, 80, and 120. (ANSI B72.7 - 1971) (includes CPVC 4116)

D2241-74 Poly(vinyl chloride) (PVC) Plastic Pipe. (SDR-PR and Class T) (ANSI B72.2 - 1967)

D2464-74 Threaded Poly(vinyl chloride) (PVC) Plastic Pipe Fittings, Schedule 80. (ANSI K65.166 - 1971)

D2466-74 Socket-type Poly(vinyl chloride) (PVC) Plastic Pipe Fittings, Schedule 40.

D2467-74 Socket-type Poly(vinyl chloride) (PVC) Plastic Pipe Fittings, Schedule 80.

D2665-74 *Poly(vinyl chloride) (PVC) Plastic Drain, Waste, and Vent Pipe and Fittings. (ANSI K65.56 - 1971)

D2672-73 Bell-End Poly(vinyl chloride) (PVC) Pipe. (ANSI B72.20 - 1971)

D2729-72 Poly(vinyl chloride) (PVC) Sewer Pipe and Fittings

D2740-74 Poly(vinyl chloride) (PVC) Plastic Tubing. (ANSI B72.22 - 1971)

D2836-72 Filled Poly(vinyl chloride) (PVC) Sewer Pipe

D2949-71 Three-Inch Thin Wall Poly(vinyl chloride) (PVC) Plastic Drain, Waste, and Vent Pipe and Fittings.

D3033-73 Type PSP Poly(vinyl chloride) Sewer Pipe and Fittings.

D3034-73a Type PSM Poly(vinyl chloride) Sewer Pipe and Fittings.

D3036-73 Poly(vinyl chloride) (PVC) Plastic Line Couplings, Socket-type.

C) Chlorinated Poly(vinyl chloride) (CPVC)

D2846-73 *Chlorinated Poly(vinyl chloride) (CPVC) Plastic Hot Water Distribution Systems.

D) Polyethylene (PE)

D1248-74 Polyethylene Plastics Molding and Extrusion Materials.

D2104-74 Polyethylene (PE) Plastic Pipe, Schedule 40. (ANSI B72.8 - 1971)

D2239-74 Polyethylene (PE) Plastic Pipe. (SDR-PR) (ANSI B72.1 - 1967)

D2447-74 Polyethylene (PE) Plastic Pipe, Schedules 40 and 80 Based on Outside Diameter. (ANSI B72.13 - 1971)

D2609-73 Plastic Insert Fittings for Polyethylene (PE) Plastic Pipe.

D2610-73 Butt Fusion Polyethylene (PE) Plastic Pipe Fittings, Schedule 40. (ANSI K65.160 - 1971)

D2611-73 Butt Fusion Polyethylene (PE) Plastic Pipe Fittings, Schedule 80. (ANSI K65.159 - 1971)

D2683-70 Socket-Type Polyethylene (PE) Fittings for SDR11.0 Polyethylene Pipe.

D2737-74 Polyethylene (PE) Plastic Tubing.

D3035-74 Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Controlled Outside Diameter.

D3197-73 Insert-type Polyethylene Fusion Fittings for SDR11.0 Polyethylene Pipe.

D3261-73 Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing.

8.2.1.2 Specifications for Plastic Piping Solvent Cements

D2235-73 *Solvent Cement for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe and Fittings. (ANSI B72.23 - 1971)

D2564-73a *Solvent Cements for Poly(vinyl chloride) (PVC) Plastic Pipe and Fittings. (ANSI B72.16 - 1971)

D3138-72 *Solvent Cements for joining Acrylonitrile-Butadiene-Styrene (ABS) Pipe and Fittings to Poly(vinyl chloride) (PVC) Pipe and Fittings for Non-Pressure Applications.

8.2.1.3 Methods of Test of Thermoplastic Pipe and Tubing

D1180-57(1972) Bursting Strength of Round Rigid Plastic Tubing.

D1598-74 Time-to-Failure of Plastic Pipe Under Long-Term Hydrostatic Pressure. (ANSI B72.6 - 1971)

D1599-69 Short-Time Rupture Strength of Plastic Pipe, Tubing and Fittings. (ANSI K65.53 - 1971)

D2122-70 Determining Dimensions of Thermoplastic Pipe and Fittings.

D2152-67(1972) Quality of Extruded Poly(vinyl chloride) Pipe by Acetone Immersion. (ANSI B72.9 - 1971)

D2290-69 Apparent Tensile Strength of Ring or Tubular Plastics by Split Disk Method.

D2412-68 *External Loading Properties of Plastic Pipe by Parallel-Plate Loading. (ANSI B72.11 - 1971)

D2444-70 Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight) (ANSI K65.169 - 1971)

D2837-69 *Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials. (ANSI K65.153 - 1971)

D2924-71 External Pressure Resistance of Plastic Pipe.

8.2.1.4 Recommended Practices

D2153-67(1972) *Calculating Stress in Plastic Pipe Under Internal Pressure. (ANSI B72.10 - 1971)

D2321-72 *Underground Installation of Flexible Thermoplastic Sewer Pipe. (ANSI K65.171 - 1971)

D2657-67(1972) Heat Joining of Thermoplastic Pipe and Fittings. (ANSI B72.17 - 1971)

D2749-68(1973) *Standard Symbols for Dimensions of Plastic Pipe Fittings. (ANSI K65.58 - 1971)

D2774-72 *Underground Installation of Thermoplastic Pressure Piping.

D2855-73 *Making Solvent Cemented Joints with Poly(vinyl chloride) (PVC) Pipe and Fittings. (ANSI K65.55 - 1971)

D3140-72 Flaring Polyolefin Pipe and Tubing.

D3311-74 Drain, Waste and Vent (DWV) Plastic Fitting Patterns.

F402-74 Safe Handling of Solvent Cements Used for Joining Thermoplastic Pipe and Fittings.

Besides these standards for the common residential plastics pipes, there are ASTM Standards listed for cellulose-acetate-butyrate (CAB), polybutylene (PB), and Styrene-Rubber (SR), thermoplastic pipes and fittings, and reinforced thermosetting plastic pipe and fittings.

8.2.2 Federal Specifications

Specifications Sales (3FRSBS)
Building 197
Washington Naval Yard
General Services Administration
Washington, D.C. 20407

L-F-1546A Fittings, Plastic Pipe (Adapters, Couplings, Elbows, and Tees for Polyethylene Pipe) (9-18-73)

L-P-315c Pipe, Plastic (Polyethylene, PE, SDR-PR) (5-3-72)

L-P-320b Pipe and Fittings, Plastic (PVC, Drain, Waste and Vent) (3-8-73), Notice 1 (5-14-73)

L-P-322b Pipe and Fittings, Plastic (ABS, Drain, Waste and Vent) (5-4-73)

8.2.3 Department of Defense Military Standards

Commanding Officer
Naval Publications and Forms Center
5108 Tabor Avenue
Philadelphia, Pennsylvania 19120

<u>MIL-P-14529B</u> Pipe, Extruded, Thermoplastic (5-6-70)

<u>MIL-P-21922A</u> Plastic Rods and Tubes, Polyethylene (7-11-66)

<u>MIL-A-22010A(1)</u> Adhesive, Solvent-Type, Polyvinyl chloride (2-17-61) Amendment (6-9-61)

<u>MIL-P-22011A</u> Pipe Fittings, Plastic, Rigid, High Impact, Polyvinyl chloride, (PVC) and Poly 1, 2, - Dichloroethylene (1-13-69)

<u>MIL-P-22634A</u> Pipe and Pipe Fittings, Polyethylene, for Low-Pressure Waste and Drainage Systems (2-11-66)

<u>MIL-P-82056(1)</u> Pipe and Pipe Fittings, Plastic, for Drain, Waste and Vent Service (1-29-68) and Amendment (5-27-69)

8.2.4 NBS Product Standards

<u>NBS Product Standard PS10-69</u> Polyethylene (PE) Plastic Pipe (Schedule 40-Inside Diameter Dimensions). (ASTM D 2104-74; ANSI B 72.8 - 1971)

<u>NBS Product Standard PS11-69</u> Polyethylene (PE) Plastic Pipe (SDR). (ASTM D 2239 - 74; ANSI B 72.1 - 1967)

<u>NBS Product Standard PS 12-69</u> Polyethylene (PE) Plastic Pipe (Schedules 40 and 80 - Outside Diameter Dimensions). (ASTM D 2447-74; ANSI B 72.13 - 1971)

<u>NBS Voluntary Product Standard PS 18-69</u> Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe (Schedules 40 and 80). (ASTM D 1527-73a; ANSI B 72.5 - 1971)

<u>NBS Voluntary Product Standard PS 19-69</u> Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe (Standard Dimension Ratio). (ASTM D 2282-73a; ANSI B 72.3 - 1967)

<u>NBS Voluntary Product Standard PS 21-70</u> Poly(vinyl chloride) (PVC) Plastic Pipe (Schedules 40, 80 and 120). (ASTM D 1785-68; ANSI B 72.7 - 1971)

<u>NBS Voluntary Product Standard PS 22-70</u> Poly(vinyl chloride) (PVC) Plastic Pipe (Standard Dimension Ratio) (ASTM D 2241-74; ANSI B 72.2 - 1967)

Note: NBS Product Standards for plastic pipe listed above are no longer available. The corresponding ASTM standard and the related American National standard are provided here for cross-reference.

8.2.5 FHA/HUD

Materials Acceptance Section, FTEX
Federal Housing Administration
Washington, D.C. 20412

FHA MR-562 *Rigid Chlorinated Polyvinyl Chloride (CPVC) Hi/Temp Water Pipe and Fittings (11-3-67)

FHA MR-563 *PVC Plastic Drainage and Vent Pipe and Fittings (11-6-67)

FHA UM-26c *Plastic Drain and Sewer Pipe and Fittings (12-7-71)

FHA UM-31e *Polyethylene Plastic Pipe and Fittings for Domestic Water Service (8-1-66)

FHA UM-41a PVC Plastic Pipe and Fittings for Domestic Water Service (4-15-69)

FHA UM-43 Acrylonitrile-Butadiene-Styrene Plastic Pipe and Fittings for Domestic Water Service (11-1-66)

FHA UM-49 *ABS and PVC Plastic Drainage and Vent Pipe and Fittings, FHA 4550.49 (5-1-68)

FHA UM-53a *Polyvinyl chloride Plastic Drainage, Waste, and Vent Pipe and Fittings (2-22-71)

FHA UM-54 ABS (Acrylonitrile-Butadiene-Styrene) Plastic Drainage, Waste, and Vent Pipe and Fittings (2-20-70)

FHA UM-56 Polyethylene Plastic Drainage Waste and Vent Pipe and Fittings (5-5-70)

FHA UM-61a (CPVC) Hot and Cold Water Distribution Systems - Chlorinated Poly(vinyl chloride) (8-20-71)

HUD Minimum Property Standards, Volume 1, One and Two Family Dwellings, 1973 Edition, No. 4900.1

HUD Minimum Property Standards, Volume 2, Multifamily Housing, 1973 Edition, No. 4910.1

HUD Minimum Property Standards, Volume 3, Care-Type Housing, 1973 Edition, No. 4920.1

Note: The Minimum Property Standards are sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

8.2.6 ANSI

American National Standards Institute
1430 Broadway
New York, New York 10018

In the ANSI classification plastic pipe standards are found in the B72 and the K65 series. For each standard currently cataloged in these series there is an ASTM standard which is either identical or more recently updated. To conserve space, the standards have been listed under the ASTM grouping with a cross reference to the ANSI designation.

8.2.7 NSF

National Science Foundation
NSF Building
Ann Arbor, Michigan 48105

NSF Standard No. 14 Thermoplastic Materials, Pipe, Fittings, Valves, Traps and Joining Materials (October 1965).

NSF Seal of Approval Listing of Plastic Materials, Pipe, Fittings and Appurtenances for Potable Water and Waste Water (NSF Testing Laboratory) (Issued in March each year).

8.2.8 IAPMO

International Association of Plumbing and Mechanical Officials
5032 Alhambra Avenue
Los Angeles, California 90032

IAPMO IS-1-71 Installation Standard for Non-Metallic Building Sewers

IAPMO IS-5-71 Installation Standard for ABS Building Drain, Waste and Vent Pipe and Fittings

IAPMO IS-7-71 Installation Standard for Poyethylene Building Supply for Water Service and Yard Piping

IAPMO IS-8-71 Installation Standard for Solvent Cemented PVC Pipe for Water Service and Yard Piping

IAPMO IS-9-71 Installation Standard for PVC Building Drain, Waste and Vent Pipe, and Fittings

IAPMO PS 17-71 Supplemental Standard to ASTM D2661-68 Acrylonitrile-Butadiene-Styrene (ABS) Plastic Drain, Waste and Vent Pipe and Fittings and Addendum

IAPMO PS 24-71 Polyethylene Pipe for Cold Water Service and Yard Piping

IAPMO PS 25-69 Fittings for Joining Polyethylene Pipe for Water Service and Yard Piping

IAPMO PS 27-69 Supplemental Standard to ASTM D2665: Poly(vinyl chloride) (PVC) Plastic Drain, Waste and Vent Pipe and Fittings.

Note: IS=installation standard; PS=product standard.

8.2.9 CSA

Canadian Standards Association, Inc.
178 Rexdale Boulevard
Rexdale, Ontario, Canada, M9W1R3

B 137.0-1973 Definitions, General Requirements and Methods of Testing for Thermoplastic Piping

B 137.1-1970(R-71) Polyethylene Pipe for Cold Water Service

B 137.2.1-1970 Acrylonitrile-Butadiene-Styrene (ABS) Pipe for Pressure Application, IPS Dimensions

B 137.3-1972 Rigid Poly(vinyl chloride) (PVC) Pipe for Pressure Application

B 137.6-1971 Chlorinated Poly(vinyl chloride) (CPVC) Plastic Piping for Hot and Cold Water Distribution Systems

B 181.1-1973 Acrylonitrile-Butadiene-Styrene Drain, Waste and Vent (ABS-DWV) Pipe and Pipe Fittings

B 181.2-1973 Poly(vinyl chloride) Drain, Waste and Vent Pipe and Pipe Fittings

B 181.11-1967(R 70) Recommended Practice for the Installation of ABS Drain, Waste and Vent Pipe and Pipe Fittings

B 181.12-1967(R 70) Recommended Practice for the Installation of PVC Drain, Waste and Vent Pipe and Pipe Fittings

B 181.1-1967 Plastic Drain and Sewer Pipe and Pipe Fittings for Use Underground

B 182.11-1967 Recommended Practice for the Installation of Plastic Drain and Sewer Pipe and Pipe Fittings

8.2.10 PPI Technical Reports

Plastics Pipe Institute
250 Park Avenue
New York, New York 10017

TR1-NOV 1968 A Glossary of Plastics Piping Terms

TR2-OCT 1968 Recommended Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe. (Replaced by ASTM D2837 - 69)

TR3-AUG 1973 Policies and Procedures on Developing Recommended Hydrostatic Design Stresses for Thermoplastic Pipe

TR4-MAR 1974 Recommended Hydrostatic Strengths and Design Stresses for Thermoplastic Compounds

TR5-MAY 1974 List of Standards for Plastic Piping

TR6-FEB 1968 Recommended Standard Terminology for Dimensions of Plastic Pipe Fittings. (Replaced by ASTM D2749 - 68(1973)

TR7-MAR 1968 Recommended Method for Calculation of Nominal Weight of Plastic Pipe

TR8-APR 1968 Polyethylene Piping Installation Procedures

TR9-AUG 1973 Recommended Standard Service (Design) Factors for Pressure Applications of Thermoplastic Pipe Materials

TR10-FEB 1969 Recommended Practice for Making Solvent-Cemented Joints with PVC Pipe and Fittings

TR11-FEB 1969 Resistance of Thermoplastic Piping Materials to Micro- and Macro-Biological Attack

TR12-APR 1973 Acrylonitrile-Butadiene-Styrene Plastic (ABS) Piping Installation Procedures

TR13-AUG 1973 Polyvinyl chloride (PVC) Plastic Piping Design and Installation

TR14-MAR 1971 Water Flow Characteristics of Thermoplastic Pipe

TR15-AUG 1973 Recommended Practice for Bending Polyvinyl Chloride (PVC) Conduit in the Field

TR16-AUG 1973 Thermoplastic Water Piping Systems

TR17-AUG 1972 Thermoplastic Piping for Swimming Pool Water Circulation Systems

TR18-MAR 1973 Weatherability of Thermoplastic Piping

TR19-AUG 1973 Thermoplastic Piping for the Transport of Chemicals

TR20-SEPT 1973 Joining Polyolefin Pipe

TR21-SEPT 1973 Thermal Expansion and Contraction of Plastic Pipe

8.2.11 PPI Technical Notes

TN1-Mar 1970 Sealants for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Piping

TN2-MAR 1970 Sealants for Polyvinyl chloride (PVC) Plastic Piping

TN3-MAY 1971 Electrical Grounding

TN6-MAR 1972 Recommendations for Coiling Polyethylene Plastic Pipe and Tubing

TN7-SEPT 1973 The Nature of Hydrostatic Time-to-Rupture Plots

TN8-AUG 1973 Making Threaded Joints with Thermoplastic Pipe and Fittings

TN9-AUG 1973 Recommendations for Coiling Poly(vinyl chloride) (PVC) Plastic Pipe and Tubing

8.3 Bibliography On Design And Installation Detail

8.3.1 ABS Council (or ABS Institute)

ABS DWV Plastic Pipe Manual, The ABS Council, 1967

The Control of Drainage - System Expansion in Multi-Story Buildings, Bull. No. 102, The ABS Institute

Chemical Resistance of ABS Drainage System, Bull. No. 103, The ABS Institute.

8.3.2 Company Publications

PVC Engineering Data, Borg-Warner Corp., LC No. 79108667, 1969

Plastic Piping Handbook, Cabot Corporation

Resistance of PVC Pipe to Attack from Termites, Rodents, and Bacteria, B.F. Goodrich Chemical Company, 1965

Fire Characteristics of Rigid PVC - DWV Piping, B.F. Goodrich Chemical Company

Technical Data, Rogod Extrusion Compound, Geon 85092, B.F. Goodrich Chemical Company

Hi-Temp Geon, Vinyl, A Material for Water Distribution Piping, TSR 68-08, TF117 and 923, B.F. Goodrich Chemical Company

All-Vinyl Plumbing - A New Dimension in Rehabilitation Construction, Building Products Newsletter, Vol. III, No. 1, B.F. Goodrich Chemical Company

Engineering and Installing Hi-Temp Geon CPVC Hot and Cold Water Distribution Systems, TSR 67-09, TF117, B.F. Goodrich Chemical Company

Installation Instructions for PVC Drain, Waste and Vent Systems, TSR 69-08, TF923, B.F. Goodrich Chemical Company, July, 1969

Effect of Chemical Cleaning Reagents on Materials Used for DWV (weight change), B.F. Goodrich Chemical Company

Derivation of ASTM D2846-69T Specification for CPVC Hot Water Distribution Systems, B.F. Goodrich Chemical Company

Installing Vinyl (CPVC) Piping for Hot and Cold Water, B.F. Goodrich Chemical Company

Fact-Finding Investigation of Genova "Thin-Wall" PVC-DWV Piping Including "in-wall" 3-inch Size, LO 4000-362, CSA Testing Laboratories.

8.3.3 State of New York

New York State Building Code Technical Report No. 3, Recommendations for Use of Plastic Piping for Drainage and Vent Systems in Buildings, Louis S. Nielsen, P.E., August, 1966.

8.3.4 University, Government and Quasi-Government Publications

Thermoplastic Piping for Potable Water Distributing Systems, Final Draft, Technical Report No. 59, Report of FCC Task Group T-52, Building Research Advisory Board - NRC/NAS, 1970.

Evaluation of ABS and PVC Rigid Thermoplastic Pipe and Fittings for Use in Drain, Waste and Vent Systems Under the Ohio Building Code, Professor R. W. Bletzaker, Ohio University Engineering Experimental Station, 1966.

8.3.5 Miscellaneous

Hydrostatic Strength and Design Stresses for Thermoplastic Pipe with Water. Reprint from Simulated Testing in the Plastics Industry, Special Technical Bulletin No. 375, published by ASTM, Frank W. Reinhart, 1965

An Investigation as to the Performance of Plastic Drainage Systems in Europe, Address by Rep. Nichols of Alabama, The Congressional Record, December 17, 1970

Test: To Determine Effect of an Undersized (Smaller diameter than inside diamater of pipe and fittings) Electrical Sewer Pipe Auger on Schedule 40 PVC-I Drain, Waste and Vent Pipe and Fittings, Report to Board of Building Standards, The Building Officials Conference of Northeastern Ohio, Allen Drain Service, Kent, Ohio.

UNIT OF MEASURE AND S.I. CONVERSION FACTORS

A recent NBS document LC 1056 dated November 1974 reaffirms, clarifies and strengthens the policy of NBS to lead in the use of the metric system. In this review of existing information on the physical characteristics of thermoplastic piping, the U.S. customary units of measure appeared much more frequently in the cited literature than did the metric units. In keeping with the intent of LC 1056, the following guidelines have been adopted for this review:

1. Equations or formulas for which metric equivalents do not yet appear in the engineering literature (see section 3.6) are expressed in U.S. Customary units.

2. When measurements have been reported in the literature in U.S. customary units, the equivalent values in the International System of Units (S.I.) are reported alongside enclosed in parentheses.

3. No S.I. equivalent is required when nominal values of units appear as adjectives such as 3-inch pipe, 2 x 6-inch stud, and 2-oz. bottle.

4. The following conversion factors, from ASTM E380-74 are appropriate for units of measure that appear in this report:

   Length

   1 inch (in.) = 0.0254 metre (m)
   1 foot (ft.) = 0.3048 metre (m)

   Mass

   1 pound-mass (lbm) = .4535924 kilogram

   Temperature

   1 Degree Fahrenheit (°F) = $(1.8)^{-1}$ kelvin (K) or (°K)
   Temperature Fahrenheit (°F) = (459.67 + temp. °F)/1.8 kelvins (K)

   Time

   1 hour (h) = 60 minutes (min.) = 3600 seconds (s)

   Velocity

   1 foot per second (fps) = 0.3048 metre per second (m/s)

   Force

   1 pound-force (lbf) = 4.448222 newtons (N)
   1 inch of water column at 60°F = 248.84 pascals (Pa)

   Pressure

   1 pound-force per square inch (psi) = 6894.757 pascals (Pa)
   6.894757 kilopascals (kPa)

Volume

1 U.S. liquid gallon (gal) = 0.003785412 metre^3 (m^3)
3.785412 litres (l)

Flow Rate

1 U.S. gallon per minute (gpm) = 0.0000630902 metre^3/second (m^3/s)

= 63.0902 centimeters^3/second (cm^3/s)

= 0.0630902 litres/second (l/s)

1 cubic foot per second (cfs) = 0.02831685 metre^3/second (m^3/s)

= 28.31685 litre/second (l/s)

Energy

1 Btu (International Table) = 1055.056 joules (J)

Power

1 Btu per hour (Btu/h) = 0.2930711 watt (W)

Latent Heat of Phase Change; Energy Change per Unit Mass

1 Btu per pound mass (Btu/lbm) = 2326 joule/kilogram (J/kg)

Specific Heat; Heat Capacity

1 Btu per pound mass per °F = 4186.8 joule/kilogram-kelvin (J/kg K)

Thermal Conductivity

1 Btu-inch per hour per square foot per °F = 0.1442279 watt/meter-kelvin (W/m K)

USCOMM-NBS-DC

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. **BIBLIOGRAPHIC DATA SHEET**	1. PUBLICATION OR REPORT NO. NBSIR 74-531	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE

Review of Performance Characteristics, Standards and Regulatory Restrictions Relating to the Use of Thermoplastic Piping in Residential Plumbing

5. Publication Date: March 1975

6. Performing Organization Code

7. AUTHOR(S) Wyly, R.S.; Parker, W.J.; Rorrer, D.E.; Shaver, J.R.; Sherlin, G.C.; and Tryon, J.

8. Performing Organ. Report No. NBSIR 74-531

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

10. Project/Task/Work Unit No. 462 8387

11. Contract/Grant No. IAA H-37-72 (409)

12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)*

Office of Policy Development and Research
Department of Housing and Urban Development
Washington, D.C. 20410

13. Type of Report & Period Covered: Interim, Jan 1972-June 1974

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The paper is a review of existing information on the physical characteristics of thermoplastic piping that are of particular interest in considering its potential for use in residential, above-ground plumbing. The presentation is oriented to considerations of adequacy of functional performance of plumbing systems from the user's/owner's viewpoint in contrast with the typical product-specification oriented format reflected in current standards.

Not only are the physical characteristics emphasized that relate most directly to the determination of functional performance of installed systems, but the importance of design and installation detail in this context is discussed.

In conclusion, this review indicates the need for better use of existing knowledge as well as for some research and test development work particularly in the areas of thermal properties, response to building fires, and resistance to water hammer.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Fire performance of piping; functional performance of piping; performance characteristics for piping; thermal/structural performance of piping; thermoplastics in plumbing.

18. AVAILABILITY

[X] Unlimited

[ ] For Official Distribution. Do Not Release to NTIS

[ ] Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13

[X] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151

19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
UNCLASSIFIED	68
20. SECURITY CLASS (THIS PAGE)	**22. Price**
UNCLASSIFIED	

AMERICAN REVOLUTION BICENTENNIAL 1776-1976