NBS BUILDING SCIENCE SERIES 111

Investigation of Standards, Performance Characteristics and Evaluation Criteria for Thermoplastic Piping in Residential Plumbing Systems

U.S. DEPARTMENT OF COMMERCE • NATIONAL BUREAU OF STANDARDS

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Sponsored by

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

U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, Secretary

Dr. Sidney Harman, Under Secretary

Jordan J. Baruch, Assistant Secretary for Science and Technology

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

Issued May 1978

Library of Congress Catalog Card Number: 78-600037
National Bureau of Standards Building Science Series 111
Nat. Bur. Stand. (U.S.), Bldg. Sci. Ser. 111, **152** pages (May 1978)
CODEN: BSSNBV

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1978

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20234
SD Catalog Stock No. 003-003- Price
(Add 25 percent additional for other than U.S. mailing).

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ABSTRACT

The application of the performance concept to the evaluation of piping systems of innovative materials is explored. User needs are considered and several material-related physical parameters are studied that might be used as measures of satisfaction of the user needs.

Information was reviewed on usage, performance characteristics and standards for thermoplastic pipe and fittings, and special laboratory tests were made to study selected characteristics and test methods. A number of performance statements and evaluation methods are recommended or discussed that relate to characteristics associated with polyvinyl chloride (PVC), acrylonitrile-butadiene-styrene (ABS) and chlorinated polyvinyl chloride (CPVC). This approach was taken to illustrate the application of performance evaluation methodology to plumbing materials.

The results indicate that PVC, ABS and CPVC can be used satisfactorily in a number of residential plumbing applications if appropriate attention is given to the selection of the materials, to the design of the piping system and to important installation details. Further research and education are needed for the general application of performance evaluation methodology as a basis for wider and more uniform acceptance of the above-mentioned thermoplastics as well as other materials for plumbing piping. However, the results of this study can be useful in expediting the systematic performance evaluation of future innovative piping materials.

Key Words: Acoustical performance (plumbing piping); fire performance (plumbing piping); plumbing performance evaluation (piping); structural performance (thermoplastic plumbing piping); thermoplastic pipe usage (residential plumbing).

1. INTRODUCTION

1.1 GENERAL STATEMENT

This report describes a study on thermoplastic piping for water supply and drainage for residential buildings, conducted for the Office of Policy Development and Research, Division of Energy, Building Technology and Standards, Department of Housing and Urban Development by the Center for Building Technology, National Bureau of Standards. The objective, scope and approach are described in Sections 1.3 and 1.4.

The study involved literature review, laboratory testing and the development of comment by a number of authorities on codes, standards, design/installation and manufacturing. This final report summarizes the significant findings previously reported in greater detail and interprets the results in the context of performance evaluation methodology for innovative materials and the practical application of this concept.

1.2 BACKGROUND AND THEORY OF PERFORMANCE EVALUATION

Most of the present standards for piping materials describe and measure the physical properties of the specific material, and are utilized primarily for quality control in the manufacturing process. Generally, such product standards provide the type of requirements and tests also needed by specifiers and purchasers to describe the product and to determine whether a particular lot of pipe and fittings actually complies with the relevant specifications. However, in most instances, these product standards do not define, under conditions of use, direct measures of the probable functional, health/safety, and durability performance of installed assemblies of pipes and fittings in relation to the material characteristics. This lack of end-use performance criteria has not been recognized as a serious shortcoming in establishing acceptance where ample time was available for the accumulation of a considerable body of data on (1) the physical and chemical properties of the material as determined by the quality control type of tests, and (2) service history from field trials. This traditional approach has been useful in helping ensure durability, but has retarded the development and acceptance of innovative materials because of the long period of time required to establish acceptance. For this reason, performance evaluation methods are needed that are generally applicable to any material irrespective of its composition. These methods should include short term tests or other suitable procedures for obtaining realistic estimates of the adequacy of performance over the reasonable life expectancy of the proposed installation. The term "performance" used in this context means the degree of satisfaction of the basic user needs for hydraulic and pneumatic functional adequacy, for health and safety, and for durability and maintainability. Thus, a viable performance evaluation methodology for innovative materials must include test procedures that effectively simulate critical effects of the service

- PREDICTION OF PERFORMANCE OF INNOVATIONS: EVALUATION TECHNIQUES
  - BY COMPUTATION (FROM THEORY OR MATHEMATICAL MODEL)
  - BY SIMULATIVE SERVICE TEST
  - BY SOME OTHER SUITABLE, SYSTEMATIC EVALUATION PROCEDURE
- INSTALLATION STANDARDS: COMPONENT INTERACTION
  - SYSTEM PERFORMANCE DEPENDS ON INTERACTIONS BETWEEN PARTS
  - INTERACTIONS DEPEND ON INSTALLATION DETAILS
- ACCEPTANCE PROTOCOL: IMPLEMENTATION AIDS
  - PERFORMANCE LANGUAGE SUPPLEMENTING THE TRADITIONAL SPECIFICATION LANGUAGE
  - GENERALLY RECOGNIZED STANDARDS THAT ENSURE ESSENTIAL PERFORMANCE
  - A CERTIFICATION SYSTEM AND ACCREDITED TESTING AGENCIES
  - CATALOG OF ACCEPTABLE SOLUTIONS

Figure 1. Basic needs in developing and implementing the performance approach

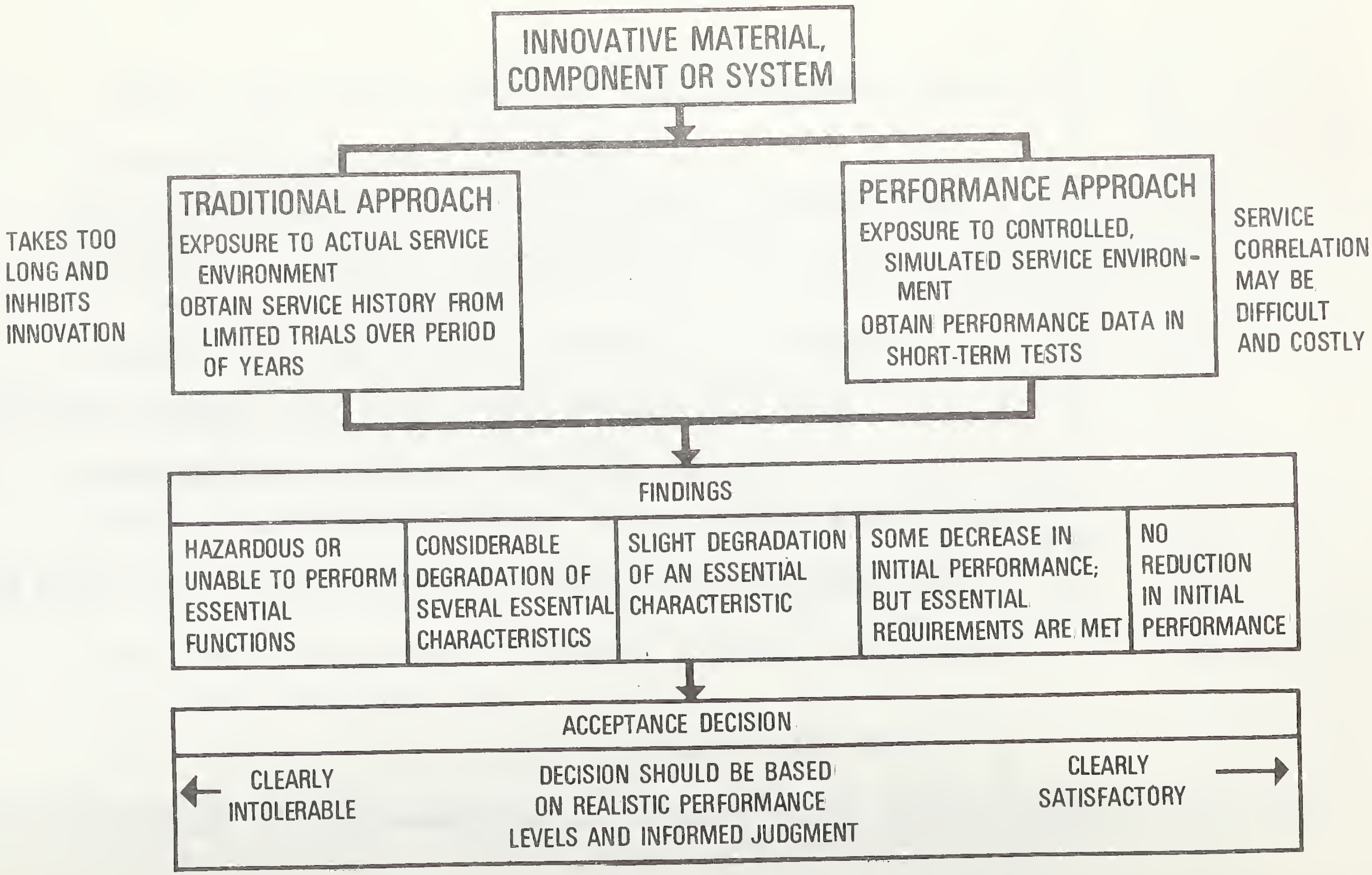

Figure 2. The dilemma of durability evaluation

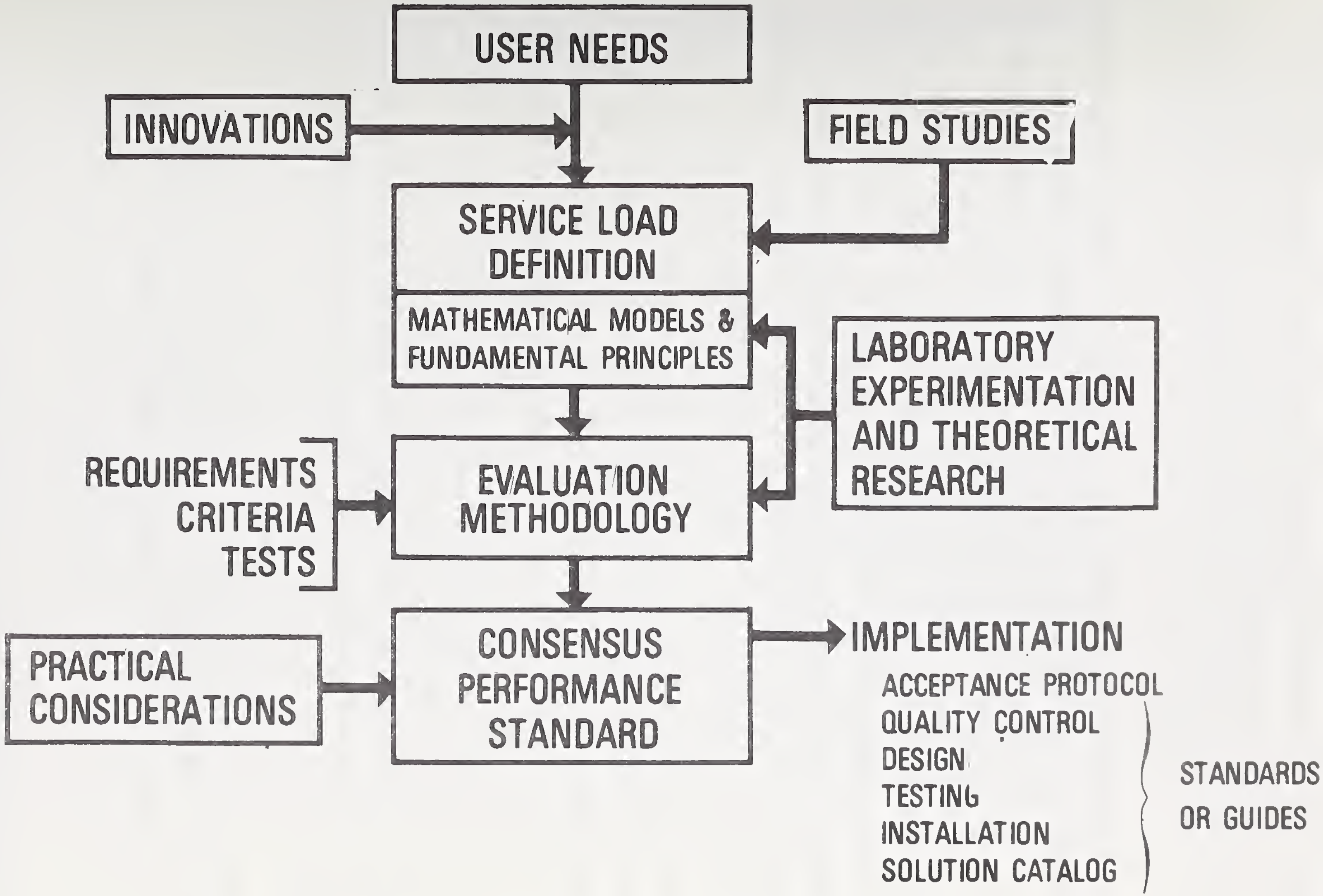

Figure 3. Model for performance evaluation

environment. This implies a need for correlation between the results of the short-term tests and long-term performance in service. This will be referred to as the dilemma of durability evaluation. Figure 1 summarizes the basic needs in developing and implementing the performance approach.

The dilemma of durability evaluation is depicted in Figure 2. Regardless of whether the traditional or the performance approach is used, the acceptance decision involves some judgment, particularly where laboratory tests or field trials show measurable degradation of one or more essential properties or performance characteristics. Figure 3 depicts a broad approach to performance evaluation, showing the basic elements of performance evaluation and its implementation. For a more detailed discussion of the performance approach for water supply and drainage for buildings, and for a bibliography on performance concepts, criteria and standards, the reader is referred to recent papers [1, 2, 3].[1]

The widespread use of performance-type standards would not eliminate the necessity for product standards. The use of 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 and components. In establishing meaningful performance tests, it might also be necessary to conduct additional special tests to study the properties of the <u>system</u> in which the materials and components might be used.

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.

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[1] Numbers in brackets refer to the list of references in Section 7.

There appears to be a trend to larger components and prefabricated or factory assembled systems to speed on-site construction and reduce cost. Contributing to this trend, and to increase usage of thermoplastic piping are considerations relating to convenience of manufacture and assembly as affected by the properties of the materials used.

Improved evaluation methodology is needed as an aid in determining whether innovative materials will be satisfactory throughout the planned lifetimes of the systems and components in which they are used. Because piping systems of traditional materials have been generally acceptable, there is a strong tendency to evaluate new materials by comparing some of the favorable properties of the traditonal materials with the corresponding properties of the new materials. This approach can exclude from consideration some of the favorable properties of the new materials that should be considered in the design of a piping system using such materials. Such an approach restricts the scope of the evaluation and may be misleading to the extent of unwarranted exclusion of innovative materials and methods. Of course, the real concern should be whether or not the performance of the plumbing system, as installed, satisfies essential user needs 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 first. Then, evaluative techniques may be developed systematically to determine the adequacy of the performance of the new materials under typical end use conditions as parts of a plumbing system. The materials with which this study has been primarily concerned are: (1) acrylonitrile-butadiene-styrene (ABS)[2] and (2) polyvinyl chloride (PVC)[2], both used where plastics are approved for drain, waste and vent (DWV)[2] systems, but PVC to a lesser extent than ABS, and (3) chlorinated polyvinyl chloride (CPVC)[2] more recently introduced for use in hot and cold water distribution systems where plastics are approved for this application.

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[2] These and other acronyms and terms have been defined in the Appendix, Section 8.1.

Piping of thermoplastic materials exhibits characteristics different from piping constructed of the traditional metallic materials. Some of these characteristics yield advantages, but others may lead to difficulties if appropriate account is not taken of them.

Any thermoplastic material, by definition, softens if its temperature is raised above some characteristic value; this value is much lower than the temperature needed to soften any of the traditional metallic materials. Within the piping structure when thermoplastic materials are used, there is greater movement under dynamic hydraulic and thermal loading and, in addition, there may be some relatively small but measurable long term change in dimensions. Plastic piping is highly resistant to corrosion of types that frequently attack metals, but some thermoplastics have exhibited environmental stress cracking and chemical attack in tests simulating what seem to be extreme service conditions for residential plumbing. Because the thermoplastics being used for plumbing piping may decompose when exposed to fire, the presence of toxic combustion products in buildings fires and the possible effect on fire spread should be taken into account in design and installation. Thermoplastics may be cut, scratched or abraded by sharp, hard objects more readily than the traditional metals, but the tools and expertise needed to avoid such potential damage during installation and maintenance are now generally available.

An attractive feature of thermoplastic piping is its light weight which reduces structural loads 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, where these characteristics are ignored the greater movements under hydraulic and thermal loads can create acoustical problems from pipe impact or from localized contact with the building structure. Recommendations have been developed on design and installation details that make it possible to avoid significant acoustical problems. See the Appendix, Section 8.3.

Care in supporting thermoplastic pipe is required because of the tendency of the pipe to deflect when exposed to hot water. If the pipe is not adequately supported and adequate provisions are not made to accommodate the expansion, contraction and long term dimensional changes that may occur in response to thermal loading, then two potential problems may arise: (1) change in drainage slope and (2) unusual stress loadings which are difficult to predict. However, the information and expertise exists to prevent or minimize such difficulties with the current materials. See the Appendix, Section 8.3.

In specifying any innovative piping material, the service conditions that are anticipated should be carefully evaluated in relation to its particular properties. For example, damage might occur in laboratory experimentation in which high concentrations of certain drain cleaning agents or other chemicals remain in contact with thermoplastic piping for unusually long periods of time without dilution or flushing out with water. However, because these conditions are unlikely to occur in actual residential use, they need not be given much weight in the selection of a material. For detailed information on chemical substances that might affect thermoplastics under some conditions, the reader is referred to an earlier report [4] and to industry literature referenced in the appendix of the present report, Section 8.3.

A considerable technology has evolved since the first polyvinyl 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 the late 1940's. There has been a gradual improvment in important properties and material consistency through research, quality control and product standards. Improvements in these areas and in design and installation standards for particular applications have led to an increase in its acceptance by designers, contractors, and building code officials. See Section 2 for a review of usage and acceptance.

Instances of faulty performance and of reluctance in acceptance, particularly when thermoplastics were first introduced, may have been related to one or more of several factors:

(1) Plastics, a generic term, refers to large number of materials whose compositions and characteristics were not well known, and whose advantages and limitations for typical installations were not understood by residential plumbing system designers and installers.

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

(3) The system characteritsics of expansion and contraction, deflection and change in slope, and the consequential requirements for jointing and support were not sufficiently well defined and documented for practical application by designers, installers and inspectors.

(4) The potential fire hazard and the potential smoke and toxic gas hazard were not considered. This may have been related to the fact that the early trials in residential plumbing applications were made in one and two story single family detached dwellings not fire-rated by the building codes, and to the fact that the added fire load due to plastic piping is small in relation to wood, furniture and other combustibles normally present in a house.

(5) The matching of material properties to user requirements could not be done systematically because of lack of specific knowledge needed to establish meaningful correlation between the test requirements of the product standards and the service performance essential to satisfy user needs.

1.3 OBJECTIVE AND SCOPE

As a part of the HUD long range research program for improving building standards and performance evaluation methodology, a broad general task was sponsored for NBS to develop performance criteria for piping materials for use in residential plumbing systems. Because of the constraints of time and costs, the laboratory work was limited to thermoplastic materials. Initially the items of interest were: "thin-wall" PVC drain-waste-vent systems constructed in accordance with criteria for "single-stack" drainage, and water distribution systems of CPVC. The findings on single-stack drainage, an issue not significantly related to the properties of materials, have been reported separately [5] and hence will not be discussed here. "Schedule 40" PVC and ABS DWV and "thin-wall" PVC DWV piping materials were evaluated in laboratory tests, and tests were made on CPVC water distribution piping materials. Some measurements were made of the thermal properties of polybutylene (PB) materials, also.

The principal objectives of this study were as follows:

1. To describe the current status of standards for, and of the usage of, thermoplastic piping, particularly for residential, above ground plumbing.

2. To identify some of the technological parameters that are involved in the development of viable performance criteria for piping materials. The emphasis was on the limited number of widely used thermoplastics, and on performance characteristics considered important for them.

3. To present a rationale and format for application of performance concepts in standards for piping in general, and, as an illustrative example, to develop a number of specific performance criteria for above ground residential plumbing piping of thermoplastics.

In this study, undertaken some time ago, thermoplastics were taken as examples of "innovative" materials because they had been more recently introduced for residential plumbing than the traditional metals. However, at the present time they have been in widespread use for a sufficient length of time to have permitted the accumulation of a significant body of service history. Because of the present wide usage of some thermoplastics for residential plumbing (e.g., PVC, ABS, PE, and to a lesser degree, CPVC), these particular materials are no longer considered "innovative" in most code jurisdictions, at least not for single family dwellings. However, because metallic piping has been used for a much longer period of time, and because of the present existence of some residual code limitations on the general use of thermoplastic piping for residential plumbing, it is helpful to utilize thermoplastics in the report for illustrating a suggested approach to the development of generally applicable performance evaluation methodology for innovative piping materials.

This report refers to a number of current model codes, and to voluntary product (quality control) standards for thermoplastic pipe and fittings. The years of issue of codes, standards and specfications referred to herein are not generally given; however, in each instance the applicable date may be taken as the most recent issue date of the code, standard or specification prior to the publication date of this report. Also, publications are referenced that provide industry recommendations and technical data on design and installation, on use limitations, and on physical and chemical properties of selected thermoplastic piping materials. A brief summary is provided in this report describing the results of laboratory tests made by NBS as a part of the study, and separately reported in greater detail [6-9].

Section 5 of the report presents performance statements for piping materials, taking into account some of the properties of thermoplastics for illustrative purposes. Had the properties of other materials been considered in detail, it probably would have been necessary to develop different criteria or test methods to address the properties that determine essential performance for those materials.

Concluding comments are given concerning the present suitability of thermoplastic piping for above ground residential plumbing, and the status of performance evaluation methodology for thermoplastic piping materials. Also, conclusions are presented concerning needs and approaches for the improvement of performance evaluation methodology applicable to any piping material.

1.4 APPROACH

Several studies were conducted in this program for investigation of performance characteristics considered especially relevant for thermoplastics piping. This final report presents in summary the results of these studies, with updating of selected topics.

The approach adopted was to review the state-of-the-art for its adequacy in terms of performance concepts and performance standards, to formulate the qualitative content of needed performance statements, and to devise and conduct a number of laboratory tests to provide a basis for test procedures and for quantification of the criteria included within the performance statements.

2. CURRENT STATUS OF THE USAGE OF THERMOPLASTIC PIPING FOR RESIDENTIAL PLUMBING

2.1 APPLICATION OF 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. Some of the determinant factors for application of these materials in plumbing systems are the temperatures where softening occurs, structural strength and dimensional stability, resistance to typical exposure to household chemicals, and cost to manufacture, fabricate and install.

Because a number of the properties of thermoplastics materials are significantly different from those of the traditional metals, the methodologies for design, specification, fabrication, installation, and cost calculation must take these differences into account.

This report is limited primarily to the consideration of the suitability PVC, ABS, and CPVC for residential plumbing and of their acceptance in plumbing codes. The most common uses of thermoplastic piping materials in residential plumbing systems are the following:

Acrylonitrile - Butadiene - Styrene (ABS): for yard piping and water service outside the building and for DWV systems.
Polyvinyl chloride (PVC): for yard piping and water service outside the building, and for DWV systems.
Chlorinated polyvinyl chloride (CPVC): for hot and cold water distribution within buildings; not widely used until recently, but now increasing in acceptance for this use.
Polybutylene (PB): for hot and cold water distribution within buildings, recently accepted for this use by some approval authorities.[3]
Polyethylene (PE): for yard piping and water service outside the building.

The usage of thermoplastic piping has greatly increased, as may be seen from the following values (of shipments) contained in AID Report [10] published in 1969 and supplemented by data from Department of Commerce Current Industrial Reports Series M30F [11]: in 1948, 0.5 million dollars; in 1957, 50 million; in 1967, 187 million, and 1972, 548 million dollars. Department of Commerce Current Industrial Report Series MA-30D(74)-1 [12] gives the following information for 1973 and 1974:

[3] A 1976 survey by the Domestic Engineering Journal (DE/Journal) showed significant numbers of approvals also for house-main water lines (water service).

Value of Shipments and Quantity of Resins Consumed for Thermoplastics Pipe, Fittings and Unions

Value of Shipments ($1,000)		Quantity of Resins (1,000 lbs)	
1973	1974	1973	1974
563, 608	699,569	1,368,038	1,341,636

The above figures evidently include thermoplastics pipe and fittings for all construction applications. Because of changes in sampling, the Department of Commerce reports Series MA-30D for 1975 and 1976 do not give product data comparable to that of 1973 and 1974.

Approximately two-thirds of the thermoplastic piping produced in the United States is used for water supply and distribution (including community and municipal systems) and for DWV piping. Figure 4 illustrates the proportions for pipe in the 1972 production of 1458 million pounds. Comparable data for the years 1973 and later were not found.

The 1975 Annual Report of the National Sanitation Foundation reported that 1975 production of thermoplastics pressure pipe and fittings for potable water was 621 million pounds, and that 1975 production of thermoplastics drain-waste-vent pipe and fittings was 258 million pounds for a total of 879 million pounds for pressure and DWV applications. The Department of Commerce Industrial Report Series M30F (73)-13 [11] reported 1,018 million pounds (value 409 million dollars) for 1973, and 924 million pounds (value 375 million dollars) for 1972. Because of probable differences in sampling, these different sources may not yield comparable data.

The generally increasing use of thermoplastic piping, particularly as indicated by the DE/Journal surveys, can be attributed in large measure to the improvements in manufacturing techniques which have created materials with greater impact strength, greater resistance to heat distortion, and improved consistency in the product. Continuing standardization and

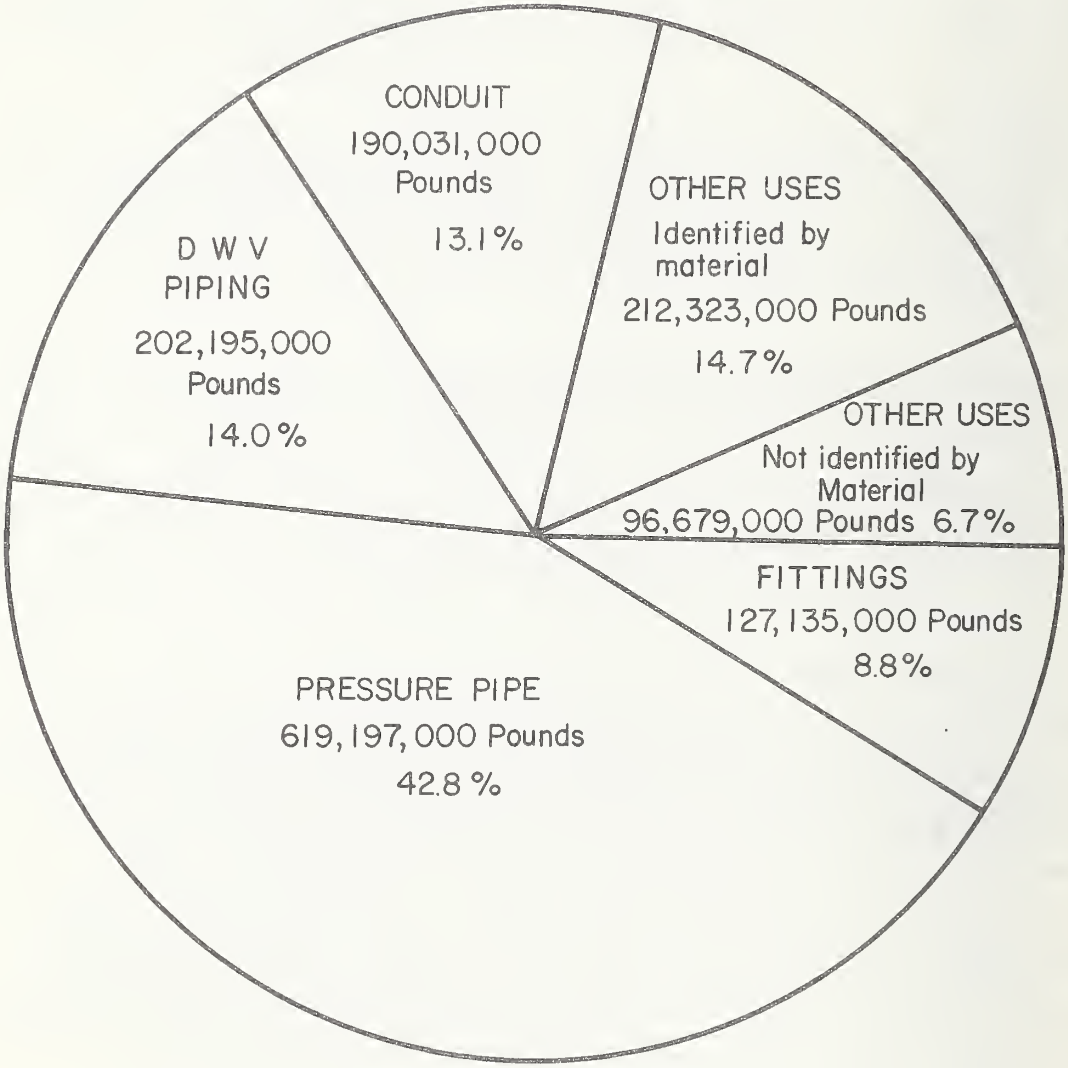

Figure 4. Production in the United States during 1972 of Thermoplastic Pipe, Tube and Fittings, Identified by End Use.

educational programs by manufacturers, and an increasing acceptance by designers, contractors and plumbing code administrators through a greater understanding of thermoplastic piping technology have also contributed to this growth.

2.2 CODE APPROVALS

In the 1960's thermoplastic piping for residential plumbing systems lacked widespread acceptance by American code authorities because metallic piping was already proven, acceptable and available, whereas thermoplastic piping was unproven in this application and many designers and installers lacked the knowledge, experience and initiative to utilize it properly. But gradually a body of supporting data has been accumulated, so that in the past few years the material has been increasingly accepted for various applications. Annual surveys by the Domestic Engineering Journal (DE/Journal) [13-16] have reported that either acrylonitrile-butadiene-styrene (ABS) or polyvinyl chloride (PVC) (usually both) has received increasing approval for drain, waste and vent (DWV) use in single family housing construction: 92% (of the municipalities participating in the survey) in 1976, 94% in 1975, 86% in 1974, 86% in 1973, 77% in 1972, 71% in 1971, 50% in 1970 and 25% in 1969. In addition, it was reported (in 1976) that PVC was permitted by 80% of local codes for DWV in low-rise apartments and 52% in high-rise apartments. The comparable figures for ABS in apartments were 80% and 50%, respectively.

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, among other things, based. In the 1973 survey [13] 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 replies to a questionnaire sent to more than 2,500 jurisdictions, the following results were obtained:

Model Code	Percentage of jurisdictions with codes "based on or identical" to model code
NSPC (National Standard Plumbing Code)	30
UPC (Uniform Plumbing Code)	22
SPC (Standard Plumbing Code)	17
BPC (Basic Plumbing Code)	15

Acceptance of thermoplastic piping for water supply is more limited than for DWV piping, according to these surveys. Where allowed for water distribution within the building, it is more often than not restricted to CPVC and when allowed underground outside the building line, (e.g. for the water service pipe) PE is frequently used.

Other plastic piping material such as PB (polybutylene) and PP (polypropylene) have recently been allowed in some applications according to Domestic Engineering Journal, and may become more widely used for residential plumbing when and if the economic factors become favorable and additional satisfactory field performance history is accumulated. In the 1976 survey, [16] 47% of the jurisdications allowed CPVC for hot/cold water distribution piping, 12% allowed PP, and 11% allowed PB. From the same survey, it was learned that 47% allowed CPVC, 31% PP and 27% PB for house-main water lines.

Table 1 provides a summary of the current extent of approval (by city codes) of several types of plastic pipe for water and DWV systems.

TABLE 1. THERMOPLASTIC PIPING USES AUTHORIZED BY LOCAL PLUMBING CODES: 1976 AND 1977. (EXCERPTS FROM TABULATIONS OF SURVEY RESULTS OBTAINED BY DOMESTIC ENGINEERING JOURNAL (DE/JOURNAL) AND PRINTED IN THE MARCH, 1976 AND MARCH 1977 ISSUES [16]

Drain-Waste-Vent lines:

	PVC DWV		ABS DWV	
	1976	1977	1976	1977
Single-family homes	92%	97%	92%	95%
Low-rise apartments	81%	83%	75%	80%
High-rise apartments	52%	66%	50%	51%
Commercial buildings	59%	59%	59%	58%

	1976	1977
House Sewer Lines:		
Schedule 40 PVC	62%	67%
Schedule 40 ABS	59%	70%
ASTM D-3034 PVC	44%	51%
House-Street Water Lines:		
Commercial-grade polyethylene	47%	34%
Premium grade polyethylene	53%	46%
Chlorinated PVC	46%	48%
Polypropylene	31%	44%
Polybutylene	27%	42%
Hot/Cold Water Distribution Lines:		
Chlorinated PVC	47%	48%
Polypropylene	12%	16%
Polybutylene	11%	19%

Table 2 summarizes the allowable uses of thermoplastics piping in water supply and sanitary drainage systems for residential plumbing, as recommended by the leading model codes and the HUD Minimum Property Standards.

Regulatory agencies that have approved the use of thermoplastics piping for plumbing have sometimes imposed limitations, e.g., height, location, type of waste, type of occupancy, fire rating of building, pipe wall thickness, special installation rules, special test requirements, combustibility, etc. Generally, regulatory agencies require that the products meet stated standards, and that design and installation conform to manufacturers' recommendations and generally accepted practice.

Table 2. ALLOWABLE USES OF THERMOPLASTIC PIPING MATERIALS FOR RESIDENTIAL PLUMBING SYSTEMS, AS RECOMMENDED BY SEVERAL AUTHORITIES (1)

AUTHORITY	MATERIAL (2)	USE (1,2)					
		POTABLE WATER PIPING			SANITARY DRAIN, WASTE AND VENT PIPING		SANITARY BUILDING SEWER
		SERVICE	DISTRIBUTION				
			UNDER SLAB	OTHER	BELOW GROUND	ABOVE GROUND	
Uniform Plumbing Code (UPC) a/ 1976	ABS	NA	NA	NA	A(3)	A(3)	A
	CPVC	NA	NA	NA	--	--	--
	PVC	A	NA	A(5)	A(3)	A(3)	A
	PVC thin wall(4)	NA	NA	NA	NA	NA	NA
	Polybutylene	A	NA	A(5)	NA	NA	NA
	Polyethylene	A	NA	A(5)	NA	NA	NA
	Styrene Rubber	NA	NA	NA	NA	NA	NA
National Standard Plumbing Code (NSPC) b/ 1975	ABS	A	--	--	A	A	A
	CPVC	--	--	A	--	--	--
	PVC	A	NA	--	A	A	A
	PVC thin wall(4)	NA	NA	NA	NA	NA	NA
	Polybutylene	NA	NA	NA	NA	NA	NA
	Polyethylene	A	NA	NA	NA	NA	NA
	Styrene Rubber	NA	NA	NA	A	NA	NA
Standard Plumbing Code (SPC) c/ 1975	ABS	A	NA	NA	A	A	A
	CPVC	A	NA	A	--	--	--
	PVC	A	NA	NA	A	A	A
	PVC thin wall(4)	NA	NA	NA	NA	NA	NA
	Polybutylene	A	NA	A	NA	NA	NA
	Polyethylene	A	NA	NA	NA	NA	NA
	Styrene Rubber	NA	NA	NA	NA	NA	NA
Basic Plumbing Code (BPC) d/ 1975	ABS	A	--	--	A	A	A
	CPVC	--	--	A	--	--	--
	PVC	A	--	--	A	A	A
	PVC thin wall(4)	NA	NA	NA	--	--	NA
	Polybutylene	A	--	A	--	--	NA
	Polyethylene	A	--	--	--	--	NA
	Styrene Rubber	NA	NA	NA	NA	NA	NA
Minimum Property Standards (MPS) e/ 1977	ABS	A(6)	NA	A(6)	A(8)	A(8)	--
	CPVC	--	A(7)	A	--	--	--
	PVC	A(6)	NA	A(6)	A(8)	A(8)	--
	PVC thin wall(4)	NA	NA	NA	NA	A	--
	Polybutylene	A	A(7)	A	A	A	--
	Polyethylene	A(5)	NA	A(6)	NA	NA	--
	Styrene Rubber	NA	NA	NA	A(5)	NA	--

A = Acceptable NA = Not Acceptable -- = Not Determined or not Applicable

Notes:

(1) Uses for condensate piping and storm water piping are not covered in this table.
(2) Must conform to applicable standards of approving authority.
(3) In residential buildings not over 2 stories in height.
(4) Defined by ASTM D2949 (3" diam).
(5) Outside dwelling only.
(6) For cold water only, outside dwelling or in unfinished basement or crawl space.
(7) Install without joints in or under slab floors.
(8) Applications limited to buildings not over six (6) floors in height, except that ABS or PVC may be used for horizontal branches in buildings of any height.

a/ Promulgated by International Association of Plumbing and Mechanical Officials (IAPMO).
b/ Promulgated by National Association of Plumbing-Heating-Cooling Contractors (NAPHCC) and the American Society of Plumbing Engineers (ASPE).
c/ Promulgated by Southern Building Code Congress International (SBCC).
d/ Promulgated by Building Officials and Code Administrators International (BOCA).
e/ Promulgated by U.S. Department of Housing and Urban Development (HUD).

3. SUMMARY OF NBS LABORATORY STUDIES

3.1 THERMAL PROPERTIES

3.1.1 Objective and Approach

The objective of the NBS work on thermal properties of plastic piping used in housing [8,9] was to investigate the sensitivity of several properties of the materials (in the form of the finished product) to temperature changes, and to provide a basis for recommended tests and performance criteria.

The approach taken was to measure selected properties as affected by changing temperature or by exposure to a given elevated temperature for various periods of time. These properties were some of those that should be reasonably stable in order to maintain design dimensions and strength over a long period of time, characteristics that are considered important to user needs such as leak resistance, drainability and hydraulic capacity. Among the material properties considered were glass transition temperature, hardness, impact resistance and permanent dimensional change on exposure to heat.

3.1.2 Scope

Measurements relating to glass transition were made on specimens of CPVC pressure tube from two manufacturers, PVC pressure pipe from one manufacturer, PB pressure tube from two manufacturers, PVC drain-waste-vent pipe from four manufacturers, and ABS drain-waste-vent pipe from four manufacturers.

Measurements of hardness as affected by temperature change were made on specimens of CPVC, PVC, ABS and PB. Izod impact resistance and hardness were also compared for these materials.

Irreversible dimensional changes from oven heating were determined for PVC and ABS drain-waste-vent pipe.

3.1.3 Test Procedures

1. Glass transition. A DuPont TMA apparatus[4] was utilized for determination of glass transition temperature, "residual stress indicator" and coefficient of linear expansion. The apparatus and test procedure have been described previously [8]. The procedure involves the measurement of the vertical displacement of a loaded probe of specified size and shape as a function of temperature,

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[4] Reference to this apparatus does not indicate NBS endorsement, nor does it imply that apparatus of other manufacture could not be used for this purpose.

time and weight when the temperature is raised slowly at a specified rate.

The glass transition temperature was taken as that temperature at which the first significant sudden change occurred in the probe position as the temperature was slowly increased. The residual stress indicator was calculated from the maximum upward displacement of the probe (before onset of apparent penetration) and the original sample thickness.

2. Hardness. The standard type D Durometer for flat specimens was adapted for use with pipe specimens maintained at a desired temperature by circulating water. This method was used for determination of hardness and hardness-temperature coefficient [9].

This method is based on the penetration of a specified indentor forced into the test specimen under specified conditions. The indentation hardness is inversely related to the penetration. The method permits measurements of either initial indentation or of indentation after a period of time.

3.2 FIRE SAFETY

3.2.1 Objective and Approach

The objective of the work on the fire performance of selected walls and chases containing DWV plumbing systems was to obtain data, under specific, controlled test conditions, on parameters similar to those that determine acceptability of walls and chases not containing plumbing. The principal questions that led to the conduct of the fire tests were:

1. Will the plastic DWV system compromise the generally accepted fire endurance ratings for constructions not containing plumbing?

2. Will the burning of the plastic piping make a significant contribution to life hazard due to the release of smoke and toxic gases?

The approach used was to apply the generally accepted ASTM E119 standard fire endurance test [17] insofar as applicable. Measures of performance taken into account in the laboratory work included fire spread, temperature rise and concentration of smoke and toxic gas in wall and chase assemblies. No flame spread tests [18] were made in this study.

The fire endurance rating of a wall or chase assembly is the time period over which the assembly is expected to act as a fire barrier to prevent the spread of fire from one room to another. The spread of fire may be due to the passage of flame or hot gases, excessive temperature rises, or structural collapse. There has been increasing evidence in recent years of the need to also consider limiting smoke and toxic gases coming into rooms adjacent to the fire.

3.2.2 Scope

Ten full scale fire tests were made involving 39 different combinations of building or plumbing construction configurations and materials [6]. Tests were made with metallic DWV systems as well as with PVC and ABS plastic DWV systems. Both chase and wall constructions were involved in the study.

3.2.3 Test Procedures

The essential features of the standard fire endurance test for walls and chases [17] were applied in these tests. The procedure involved the construction of the test wall or chase as one enclosure of a gas fired furnace, and the operation of the furnace in a manner so as to produce temperatures within the furnace in accordance with the standard ASTM E119 time-temperature curve. Temperatures were monitored with chromel-alumel thermocouples at various points on the surfaces of the pipes and fittings, in the air inside the drainage stacks and on the surfaces of the walls and chases. Gas concentrations in the wall cavities were measured by several techniques at a point one foot above the lowest fixture branch. An anemometer was used for measuring the upward flow of air induced in the stacks by the fire. At regular intervals cotton pads were placed near the unexposed surfaces to test for possible ignition from the passage of hot gases through cracks or openings.

The test criteria adopted for this study called for conformance to the following requirements during a 60 minute period at exposure to the standard time-temperature curve:

1. There should be no passage of flame or hot gases through the wall assembly containing the DWV installation that would result in the ignition of the cotton pad.

2. The temperature rise on the unexposed surface of the assembly containing the DWV installation should not exceed 181°C (325°F) at any measured point. The temperatures recorded on the laterals (fixture traps or trap arms) are not regarded as wall surface temperatures.

3. Large quantities of smoke should not pass through the unexposed face. This last criterion has not been defined in quantitative terms but was based on observations during the test that indicated when heavy smoke was seen to be issuing from the construction.

The above three criteria were used to judge the extent to which the wall assembly tested had met the requirements for the one hour fire endurance. No hose stream tests (optional in ASTM E 119) were conducted and no tests were made under conditions simulating fires in high-rise buildings.

3.2.4 Findings

Detailed findings in the NBS tests have been reported [6]. From this work, the following statements are made:

1. The PVC DWV systems with 4-inch stacks and 1-1/2-inch laterals in 20-inch by 20-inch chases met the criteria for 60 minutes fire endurance. The annular openings around the laterals were sealed with plaster spackling compound for these tests. Although not tested, it appears likely that a similar ABS installation would also meet the test criteria.

2. The one hour, fire rated walls containing ABS and PVC pipe with back-to-back laterals in line with the stack met the 60 minute criteria when all of the following conditions were satisfied:

a. The annular openings around the laterals were sealed.

b. The wall cavity depth was 5-1/2 in or more (No tests were made with 3 1/2 in cavity depth and offset laterals. The tests with 3 1/2 in cavity depth and back-to-back laterals were made with the fittings penetrating the wall membranes).

c. The stack was limited to 2-or 3-in diameter. A 4-in diameter PVC stack in a 9-1/2-in deep wall cavity also met the criteria when the annular opening around the lateral was sealed.

3. The fire endurance of the walls containing PVC or ABS pipe with back-to-back laterals in line with the stack (without horizontal offset) was reduced when any of the following conditions existed:

a. The drainage fittings (e.g., tees, wyes) penetrated the gypsum board.

b. The annular hole around the PVC or ABS lateral was not sealed.

c. The PVC or ABS pipe was used in a 3-1/2-in deep wall cavity with either wood or steel studs (see parenthetical statement in 2(b) above for explanation).

4. Offsetting the lateral from the stack in the same stud space for a 2" x 6" wood stud wall increased the time to flame passage. However, when the annular openings around the lateral were not sealed, a considerable quantity of smoke was released into the room at 34 minutes and the ABS and PVC systems failed this criterion. When the lateral was offset from the stack in an adjacent stud space, the heavy smoke criterion was reached at 5 minutes and failure by flame through occurred at 21 minutes. The effect of offsetting the laterals in 2" x 4" wood or steel stud walls was not examined in these tests.

5. The performance of the PVC systems was superior to that of the ABS systems, both in time to flame through and in time to heavy smoke development in almost all the tests where a direct comparison was possible. These tests covered a variety of wall cavity depths and stack sizes. Each comparison is based on the condition where the opening around the lateral was completely sealed off with plaster spackling. When the annular opening was not sealed, the performance was difficult to compare since the times to failure were short for both the PVC and ABS systems.

6. All copper, galvanized steel and cast iron systems installed in wall cavities, a total of seven test assemblies, met the criteria for 60 minutes in every case. In six tests, the openings around the laterals were sealed, and in one test the opening around the lateral was not sealed. The wall cavities in these tests were of three depths: 3-1/2 in, 5-1/2 in, and 9-1/2 in. While the wall surface temperature rise did not exceed 181°C (325°F) the temperature of the copper lateral reached 500°C (932°F) just outside the wall.

7. Based on the results from this series of tests, plastic DWV systems with lateral sizes of 2 inches or less would not be expected to reduce the 1-hour fire endurance rating of wood stud and gypsum board walls and chases in one and two story dwellings provided that:

a. the annular opening in the wall around the lateral is sealed (an adequate inspection system may be required), and

b. the stud space depth or orientation of the fittings is sufficient to obviate the need for the hubs of any fittings in the vertical stack to penetrate the wall (no tests were made in this program with a wall cavity depth of 3 1/2 in and without the fittings penetrating the wall membrane).

8. There was a quantitative difference in the fire performance of ABS and PVC DWV systems. However, neither system degraded the one-hour fire rating of wood stud and gypsum board walls where the conditions of item 7 above were followed.

9. This investigation covered only the fire performance of DWV systems in one-hour fire rated chases and walls. It did not address the fire performance of DWV piping in "high rise" buildings nor DWV piping pene-

trating floor-ceiling assemblies. Further studies may be needed to determine relative effects due to pressure differences from stack effect in high rise buildings. Also, there is a need for developing a suitable, reproducible procedure for quantitative measurements of smoke and gas accumulation in unexposed dwelling spaces to the space containing the fire.

3.3 RESISTANCE TO INTERMITTENT HOT-WATER EXPOSURE AND SHOCK PRESSURE (WATER HAMMER)

3.3.1 Objective and Approach

The objective of the work on resistance to intermittent exposure to hot water was to examine the effects of a simulated service exposure of an assembly of pipe and fittings. The information of principal interest was the permanent change in dimensions and the continuity of leak resistance.

The objective of the work on shock pressure was to examine the effects of simulated "water hammer" on an assembly of pipe and fittings. The information of principal interest was the ability of the assembly to withstand, without leaking, repeated applications of shock pressure for a sufficient number of times to represent the exposure anticipated over the planned life of a residential water distributing system.

3.3.2 Scope

In the hot-water exposure test, measurements were made of dimensional changes in 4 in "thin-wall" PVC DWV pipe (wall thickness approximately 0.131 in, a little thinner than SDR 32.5 as specified by ASTM D2241) and in 1/2 in CPVC water tubing (ASTM D2846) as arranged in representative assemblies. Cyclic exposure to hot water (generally 140 - 150°F/60 -66°C) flowing through the assemblies was provided for a little more than 1500 cycles for the water tubing and 750 cycles for the DWV pipe. Lateral deflections and changes in length were monitored at a number of places in the test assemblies, longitudial compressive forces were measured, and observations were made for evidence of leaking.

In the shock pressure test, measurements were made of the number of cycles to failure (up to 350,000) of CPVC water tubing, as arranged in a representative assembly. Failure in these destructive tests was indicated by rapid loss of pressure from bursting or significant leaking. Tests were made at four different temperatures; 75°F (24°C), 120°F (49°C), 140°F (60°C) and 180°F (82°C). At each temperature, the number of cycles-to-failure was determined at each of several levels of peak pressure produced by the test apparatus.

3.3.3 Test procedures

1. Hot water exposure. Because there were no standard test methods suitable for the purposes of this study, a special test was designed. This is described in some detail in another report [7]. Essentially the procedure involved exposure to flowing hot water for five minutes at 1/2 hour intervals. The apparatus was designed so that the hot water from a 52 gal water heater was delivered first to a test loop of 1/2 in CPVC water tubing, next to a 4 in PVC DWV test stack assembly from which it was discharged into a receptor, and finally returned to the heater by a high-pressure pump. Two DWV test stacks were provided - one with longitudinal expansion restraint devices spaced 9 ft (2.7 m) apart, and the other with expansion fittings that permitted longitudinal expansion without significant restraint. Four types of attachment of the water tubing loop to a simulated floor joist structure were provided - two generally accepted methods and two improper methods. The accepted constructions were (a) a 10 ft (3.0 m) straight run of piping with only one end restrained and with loosely-fitting intermediate non-metallic clamps so that longitudinal movement was not restrained, and (b) a similar assembly of piping restrained at both ends but having, in addition, an intermediate horizontal offset that accomodated longitudinal expansion and contraction through flexing at the offset section. This arrangement utilized loosely fitting non-metallic clamps except at the fixed ends. The improper constructions were (c) a 10 ft (3.0 m) straight run with loosely fitting non-metallic intermediate clamps and end restraint

at both ends and (d) a 10 ft (3.0 m) straight run with tightly fitting intermediate metallic clamps and end restraint at both ends.

The direction of flow through the water tubing test loop was reversed alternately, the first exposure designated "clockwise" and the next exposure "counterclockwise". The flow from the water tubing loop was delivered to one of the DWV stacks during the clockwise exposure and to the other stack during the counterclockwise exposure.

Longitudinal forces generated by thermal expansion in the restrained pipes were measured by load cells with a range of 500 lb f(2.224×10^3N). Surface temperatures and rises in surface temperatures were determined with maximum/minimum recording surface temperature gages with a range of 0°F to 270°F (-18°C to 132°C). Dimensional changes were determined by graduated scales or calipers placed against fixed guide-pieces at predetermined locations. Temperatures of the water were determined with bimetallic-type dial temperature gages tapped into the flow system at several points with a range of 30°F to 240°F (-1°C to 116°C). Gage pressures were determined with bourdon-type dial gages with a range of 0 to 100 psi (0 to 689 kPa). Pressure differences for flow-rate determination were measured with conventional water-over-mercury manometers.

Typically, measurements of dimensions and positions, as well as of pressures, flow rate and temperatures, were made during the last one minute of the 5 minute flow period. Dimensional and position measurements were also made at the beginning of the test before exposure to hot water and, on occasion, during extended shutdown periods, and after completion of the test. Changes in longitudinal forces in restrained pipes were measured continuously during and for a short time after the 5 minute flow period at several times during the test.

2. Shock pressure. A special test [7] was designed, because no suitable standard test method was available. The procedure involved repetitive (frequency 2 Hz) exposure to a a pre-programmed pressure

rise of short (0.16s) duration, with the test assembly and the water therein at a particular temperature. The assembly comprised two 7' - 10 1/2" (2.40 m) lengths of 1/2 in CPVC tubing (ASTM D2846) joined with a fitting (90° elbow). The objective of the test was to determine the number of exposures to a given shock pressure that could be tolerated without failure of the pipe or fitting. Various test pressures were selected, and the corresponding number of cycles-to-failure for each pressure was determined. The number of of cycles were counted up to 350,000 or until failure occurred. Tests were made at temperatures of 75°F (14°C), 120°F (41°C), 140°F (60°C) and 180°F (82°C). A total of 65 specimens were tested. The number of exposures (350,000) was selected on the basis that this is a reasonable estimate of the number of occurrences of primary shock pressure waves that might occur in the fixture supply pipe to a household plumbing appliance, e.g. the hot-water supply pipe to an automatic dishwashing machine, in a period of 50 years.

The pressure was generated by a piston, and measured with a pressure transducer. A data acquisiton system was utilized that provided for control of the piston position to maintain a pre-programmed pressure, for counting the number of pressure pulses, for monitoring the temperature and for indicating sudden loss of pressure (failure).

3.3.4 Findings

1. Hot water exposure. A report on a thermal cycle test of horizontal PVC pipe [19] was reviewed. The author concluded that a realistic limiting mid-span deflection for horizontal drainage pipe is s/48, after exposure to 73,000 cycle of exposure to 180°F (82°C) water (assumed to represent 50 years of service exposure), where s is the distance between supports. This limit, compatible with the capabilities of the 2 inch Scnedule 40 PVC pipe tested with 4 ft (1.2 m) support spacing, was considered adequate to assure continuous positive slope in nominally horizontal drains installed with the customary gradient of one in 48. A review was also made of a British Standard that described a thermal cycle test of a vertical PVC DWV stack assembly subjected to

2500 cycles of 91°C (196°F) water [20]. It was required that there be no leaks in the assembly during and after the test, and that after the test a ball 6 mm (1/4 in) less in diameter than the stack be passed. This indicates a limiting decrease in diameter of about 6 percent and a theoretical diametral difference of about 12 percent.

The NBS hot water test [7] produced the following results:

a. During 1500 cycles of exposure to water at an average temperature of 144°F (62°C), the CPVC pressure piping assemblies developed no leaks, either with recommended or non-recommended mounting techniques.

b. There were no practically significant changes in dimensions of CPVC pressure piping assemblies, or of PVC DWV assemblies, mounted in accordance with industry recommendations, either during or following exposure to 1500 cycles of 144°F (62°C) water (for the CPVC assemblies) and 750 cycles (for the PVC assemblies). There was some evidence of a slight permanent lengthening of the CPVC assemblies and a slight permanent shortening of the PVC stacks, but the measurements of this parameter were not considered sufficiently precise to warrant meaningful numerical conclusions.

c. Thermal compressive stress measured in the CPVC and PVC assemblies was far less than the usual hydrostatic tensile design stress used for pressure rated pipe of comparable wall thickness (ASTM D2846 and ASTM D2241).

2. Shock pressure. A review of the work of other investigators [21, 22, 23] indicated that the equations for "water hammer" originally developed for application to metal pipe are also applicable to thermoplastic pipe if the appropriate material-dependent coefficient is used.

One study [21] indicated that PVC 1120 160 psig[5] rated pipe may be expected to have a cyclic pressure life of the order of 250,000 to 1,000,000 cycles of peak pressure fluctuation from a static line pressure of 50 psi (345 kPa) to 160 psi (1.10 MPa) (static pressure plus shock pressure). The author recommended the consideration of a cyclic pressure design basis in a fashion somewhat similar to the customary static pressure design basis.

Another study [23] concluded that the present PVC pressure pipe is suitable for use at its rated hydrostatic pressure in systems in which flow velocities are limited to 5 fps (1.5 m/s). This study also showed that theoretical shock pressures generated in PVC pipe are less than 50 percent of those in cast iron and asbestos cement, for a given velocity.

The NBS shock pressure test on CPVC [7] showed capability to withstand in excess of 350,000 cycles of peak pressure to 150 psi at 180°F (82°C), and that a fatigue life curve of peak pressure vs number of cycles to failure can be established for a given test temperature. The test procedure used in the NBS test should be considered in the development of a standard test for shock pressure.

3.4 ACOUSTICS

Although no laboratory tests were made on the acoustics of plumbing systems as a part of the particular investigation described herein, considerable attention was given to the drafting of criteria for this purpose. Familiarity and laboratory and field experience with the test methods referred to in the Criteria had been obtained by NBS staff previously, for example in Operation BREAKTHROUGH [24, 25]. In recent years, increasing interest in the control of noise in plumbing systems has been expressed by consumers, engineers and architects. Thus, acoustic criteria are considered an important part of the performance requirements for piping in residential plumbing.

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5 Pounds per square inch gage (pressure).

4. AN APPROACH TO PERFORMANCE EVALUATION OF PIPING MATERIALS

4.1 STATUS OF TRADITIONAL METHODS OF EVALUATION

The existing methodology is characterized by two limitations, insofar as the performance approach is concerned: (1) the standards tend to describe the properties of pipes, tubes and fittings separately (and are often written around the properties of the component materials), rather than to define the performance required of the installed assembly operating in the service environment (although a recent trend to "system" standards has been noted: see Appendix, Section 8.2) 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 evaluation.

As stated in Section 1.1, this has not been recognized as a serious shortcoming under the traditional acceptance procedure where a long period of time has been available to complete the evolution of the acceptance process for new materials (see Figure 2). But this slow process needs a supplementary performance evaluation methodology if acceptance decisions are to be reached more rapidly and systematically and if innovation is to be encouraged rather than hindered.

4.2 USER NEEDS AND MEASURES OF PERFORMANCE

For a building component as thoroughly integrated into the building system generally with minimum accessibility 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 durability.

The development of performance test methods that are meaningful requires first the conception of criteria that are related directly to user requirements that are important to the developer, builder, purchaser and occupant, and then the establishment of a test method that realistically simulates 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 this information into the development of laboratory test procedures with equipment that can be described definitively, and that can measure with suitable reproducibility the effects of the simulated service exposures in quantitative terms. The broad objective is to identify suitable existing test methods wherever possible, and where there are no suitable existing tests to introduce appropriate modifications in the existing tests or to develop entirely new, performance-type tests. In the development of performance tests as well as in the analysis and interpretation of test data, panels of knowledgable specialists may be needed to facilitate effective review and purposeful decision making.

In the absence of comprehensive statistical data on use conditions, on the degradation of essential properties of materials in a service environment, 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 using performance test procedures that measure key performance characteristics. Decisions with respect to upgrading, downgrading, or maintained present quality require the studied judgment of experienced persons acting together. This need is illustrated by the great difficulty of making realistic and meaningful decisions concerning comparability of performance when inherent properties of materials being compared are quite different, as for plastics and metals. Required performance levels established in this way would, of course, be subject to later adjustment as more extensive service data and user reaction become available. The ideal alternative, beginning with the collection of comprehensive data on service conditions, installation detail, user response, etc. could be prohibitive in cost and practical difficulty.

The principal user requirements for the piping as installed in plumbing systems can be classified in three major categories; (a) hydraulic and acoustical 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 and internal shock pressure.

(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, noise reduction between spaces within a living unit through space dividers, and maximum noise levels generated in interior spaces during normal usage with typical hydraulic loads.

Performance with respect to the requirements of health and safety is determined largely by toxicological acceptability (non-transfer of hazardous or toxic materials to potable water), by fire safety factors (the spread of fire, smoke and toxic gases in building fires), and by the potential for introducing harmful chemical solutes (from the piping) into the waste discharge that are not normally removed in waste water processing plants.

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 <u>system</u>. Among the principal measures are:

(a) Resistance to the normal chemical environment sufficient to guard against excessive chemically-induced changes in strength or dimension under typical structural and thermal load patterns within the plumbing system.

(b) Resistance to the effects of repetitive thermal and structural loads, and of weathering and aging on the stability of essential dimensions and strength, and on the maintenance of leak resistance of the piping itself (including joints and connections to equipment) over an extended period of service.

(c) Resistance to abrasion or cutting from pipe hangers, guides, and supports; from typical contents transported in a normal service environment; and from mechanical pipe cleaning tools.

From the foregoing discussion, it can be seen that criteria for piping in the context of performance involves pipes, fittings, joints, and sometimes the structural interface. A knowledge of the particulars of the service environment is needed to develop viable performance criteria and evaluation methods.

4.3 FORMAT FOR PERFORMANCE CRITERIA

A framework is helpful in providing guidance both in the definition and practical application of relevant portions of the existing evaluation methodology from a performance standpoint, and in the development of the more comprehensive performance evaluation methodology that is needed. Although the present program is limited largely to specific considerations believed most relevant to thermoplastics, the approach might be applicable more broadly, with some expansion, to the determination of adequacy of performance for other new piping materials. The alternative for the evaluation of future innovative piping materials 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. In the case of thermoplastics for above-ground residential use, more than a quarter century of U.S. experience has been required to approach this level of acceptance. A more expeditious, systematic and reproducible evaluation procedure and an improved protocol for determining acceptance is needed, as illustrated in Figure 3 (See page 5) and in Figure 5.

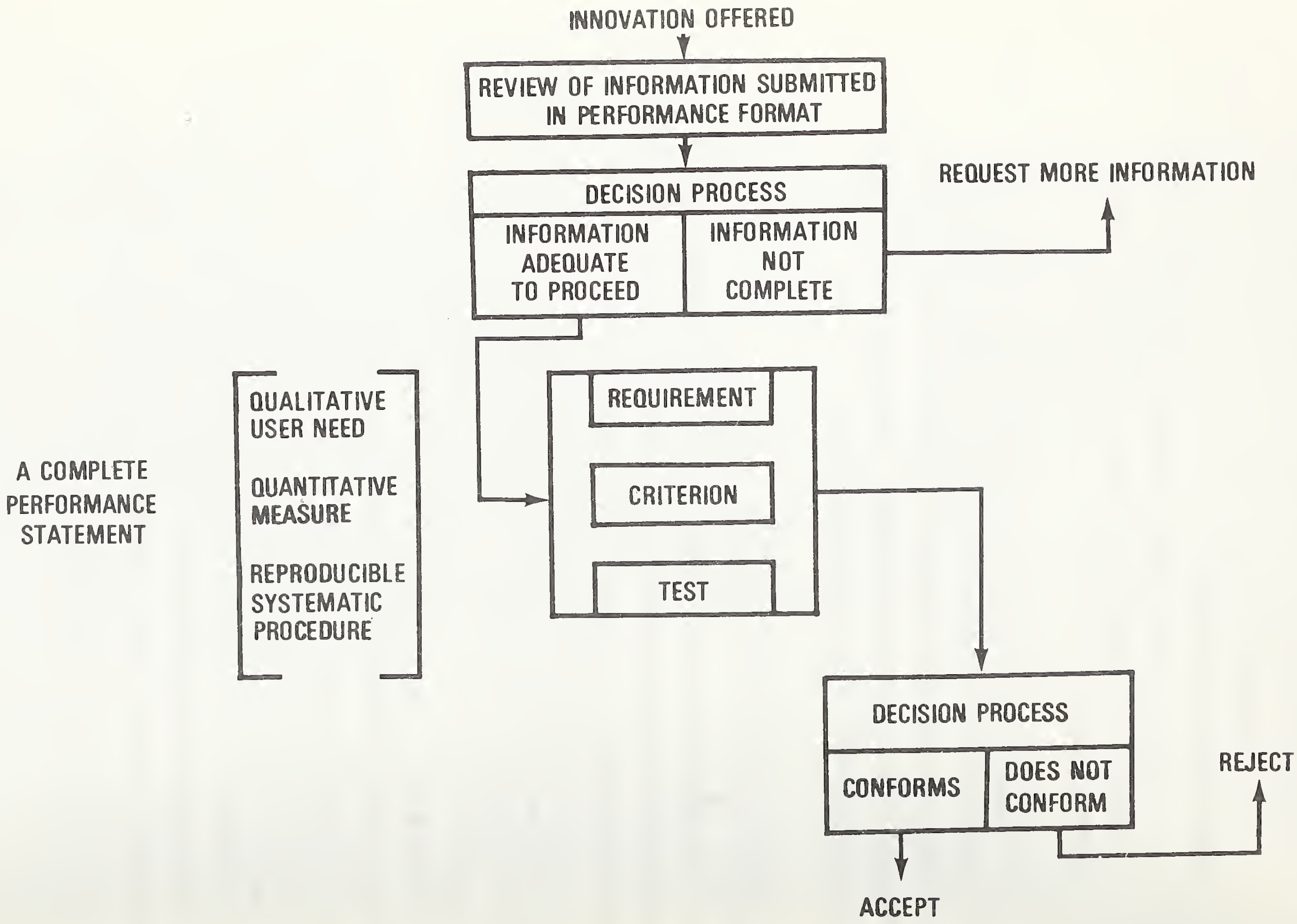


Figure 5. Essential steps in performance evaluation

Figure 6 shows a number of the key elements of performance evaluation for piping materials. In this approach, the particular requirements to be emphasized will depend on the application being considered, and the measures of performance that are critical will depend on the particular combination of performance characteristics and physical and chemical properties of the materials being considered. For example, fire spread might be a relevant measure for an assembly containing materials that are subject to burning or pyrolysis such as thermoplastics, but not necesarily so for an assembly of materials generally considered non-combustible such as steel or cast iron. On the other hand, some of the important measures for certain metals may be of little consequence for some of the non-metals, for example electrolytic corrosion and blockage attributable to corrosion processes.

Existing standards and other existing sources of information provide some complete or at least partial performance statements, either stated or implied. Unfortunately, however, this is not enough. In order to facilitate an adequate review of existing information on performance evaluation and to define residual research needs, some guides are needed. Patterned after the general hierarchy depicted in Figure 6, a matrix of the type shown in Table 3 can be helpful in the search for performance statements and in the definition of resarch needs. Table 3 emphasizes criteria applicable to non-metallic piping materials such as thermoplastics; these criteria could be suitability modified or expanded to address other materials with different properties.

The criteria developed in the present study are presented in Section 5 in sequence, using the organizational scheme depicted in Figure 6 and Table 3. The group of critiera for each attribute category is preceded by a brief introductory discussion. Each criterion is followed by a statement identifying or describing the method of evaluation, or indicating the absence of a suitable method. In instances where explanation or discussion is necessary or beneficial, a commentary is given that presents the rationale for the criterion or for the method of evaluation, or for both.

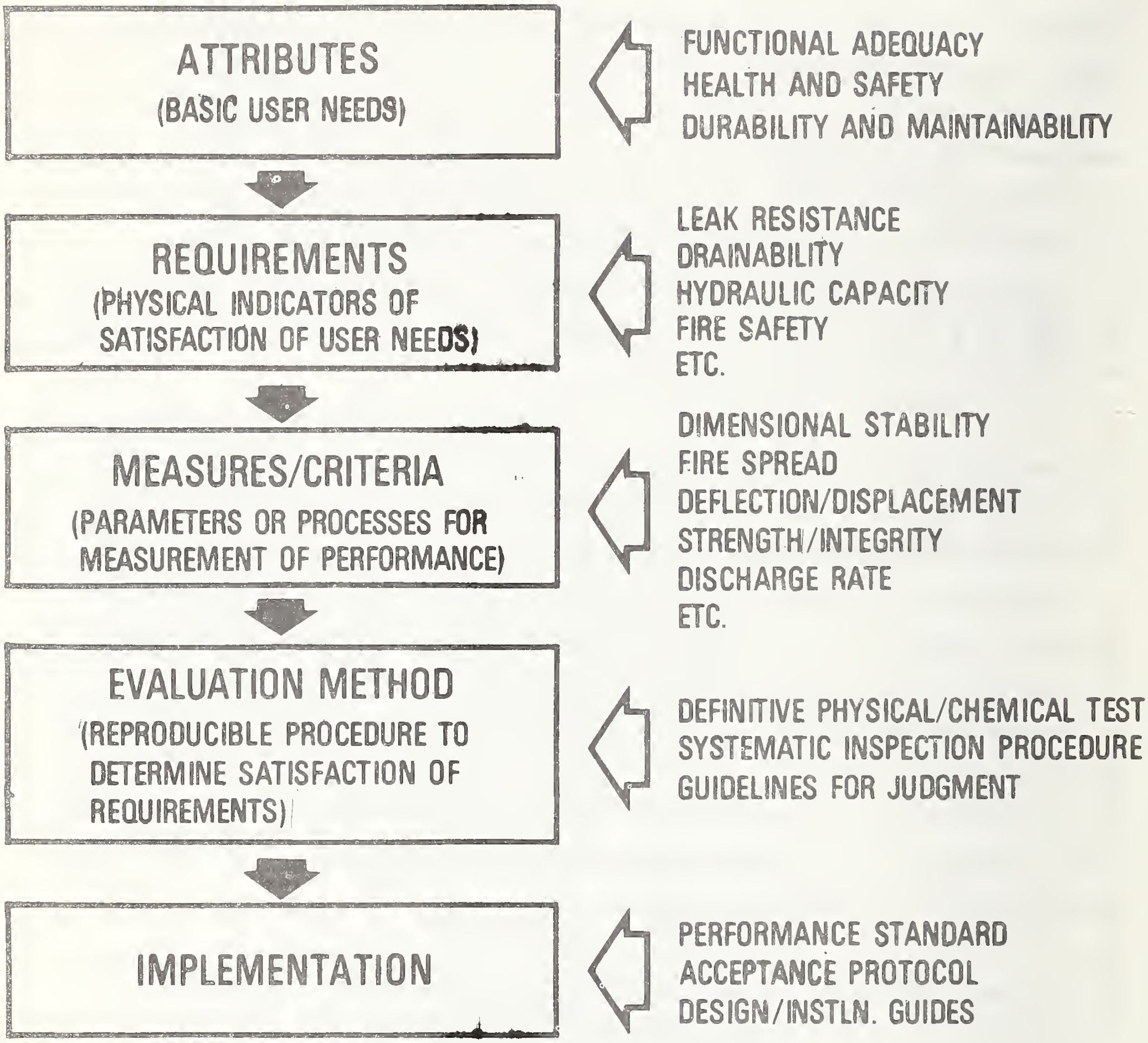


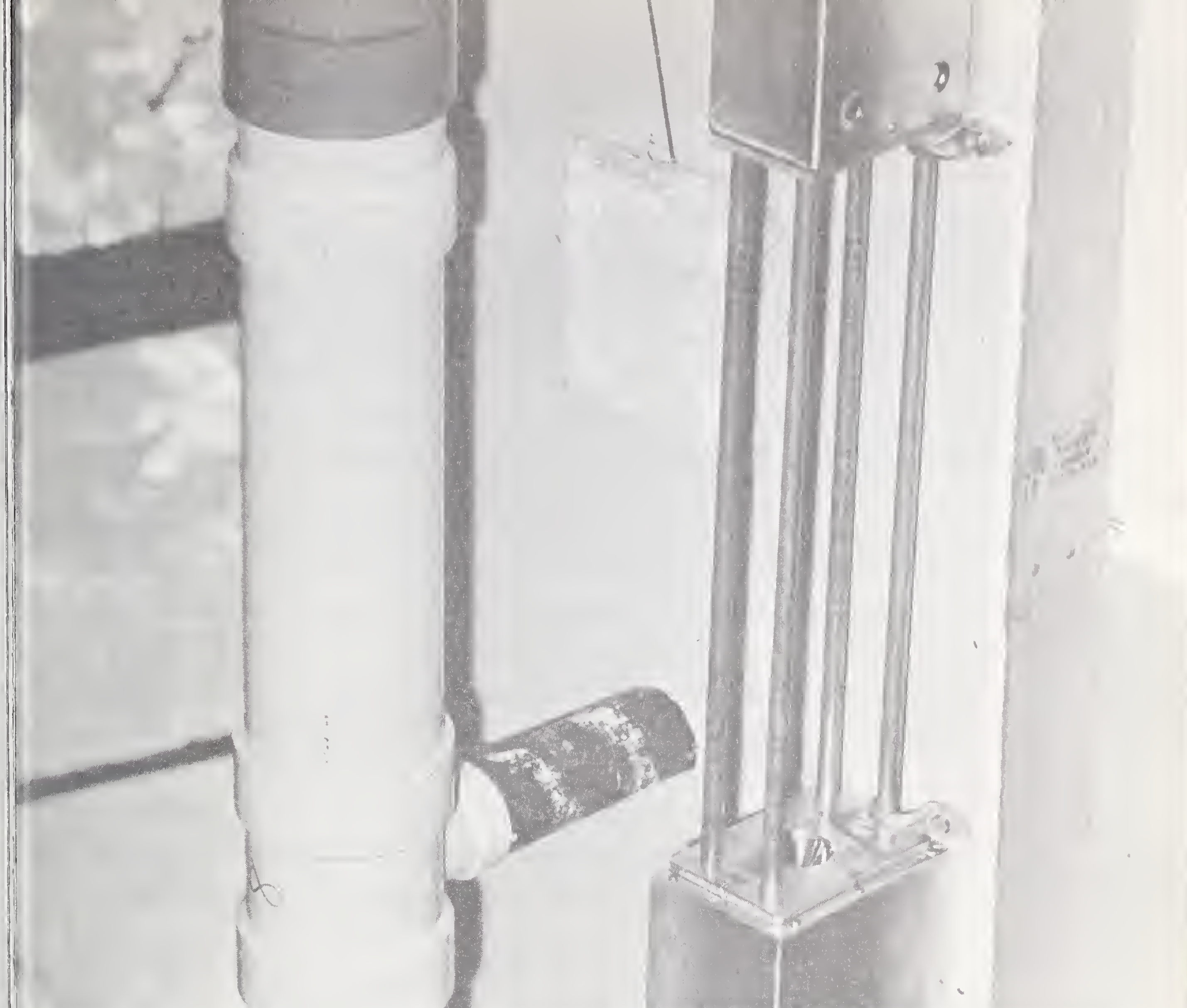
Figure 6. Classification hierachy for performance criteria for piping materials

TABLE 3. MATRIX: CRITERIA FOR PIPING MATERIALS

REQUIREMENTS	MEASURES OR CRITERIA	ATTRIBUTES	FUNCTIONAL ADEQUACY	ADEQUACY FOR HEALTH, SAFETY	ADEQUACY FOR DURABILITY, MAINTAINABILITY
Leak resistance	A.1.1	Resistance to sustained pressure	●		
	A.1.2	Resistance to shock pressure	●		
Drainability and hydraulic capacity	A.2.1	Beam/column deflection and ring distortion	●		
	A.2.2	Continuity and smoothness of interior surfaces	●		
Acoustical acceptability	A.3.1	Noise reduction between living units, through interdwelling walls containing piping	●		
	A.3.2	Noise reduction between living units, through interdwelling floor-ceilings containing piping	●		
	A.3.3	Noise reduction between spaces within a living unit, through walls and partitions containing piping	●		
	A.3.4	Noise reduction between spaces within a living unit, through floor-ceilings containing piping	●		
	A.3.5	Noise level in interior spaces during operation of plumbing system	●		
Toxicological acceptability	B.1.1	Elution of toxic substances		●	
Fire safety	B.2.1	Fire Spread		●	
	B.2.2	Spread of smoke and toxic gases		●	
	B.2.3	Flame spread		●	
Retention of properties for essential functional performance	C.1.1	Long term stability of dimensions and strength (a) dimensional change (b) strength reduction			● ●
	C.1.2	Resistance to chemical attack and environmental stress cracking			●
	C.1.3	Resistance to abrasion and cutting			●

The criteria presented in this report are not concerned with plumbing fixtures, appliances, or appurtenances, nor with characteristics that do not depend on the properties of the piping materials in some manner. The criteria are concerned with assemblages of pipes and fittings as utilized and installed in complete plumbing systems. The assemblages must be addressed by the criteria because the performance of the piping system can depend to a considerable extent on the interactions between the pipes, fittings, supports, and attachments. Traditionally, product standards have described some of the properties of pipes and fittings, but not necessarily of the assemblages as installed in plumbing systems.

The format adopted herein is intended to provide essentially a complete performance statement within each unit. That is, the basic requirement, the criterion and a method of evaluation are provided, along with essential references and helpful commentary.



5. PERFORMANCE CRITERIA FOR THERMOPLASTIC PIPING

5.1 ORGANIZATION OF THE CRITERIA

The criteria are organized according to the matrix shown in Table 3, with classification into the hierarchy categories of attribute, requirement, and measure as shown in Figure 6. Table 3 is useful in showing the relationships between the various criteria in the classification system used, and their individual relationships to the attributes, requirements, and measures. Most of the criteria presented herein have been suggested as significant for thermoplastic piping materials. If the criteria were to be expanded or modified to apply to other classes of materials, it is probable that additional or alternative key measures and test procedures would have to be identified and defined.

5.2 CRITERIA FOR FUNCTIONAL ADEQUACY

This group of criteria describes measures for assessing functional performance without particular regard to safety or durability (See Figure 6 and Table 3). This is the type of performance that is required to satisfy immediate user needs without necessarily considering those properties of materials upon which the adequacy of functional performance at some later time might depend. Examples of functional criteria for piping systms are leak resistance, hydraulic capacity and noise level.

A. Attribute: FUNCTIONAL ADEQUACY

A.1 Requirement: LEAK RESISTANCE

A.1.1 Criterion: Resistance to Sustained Pressure

Representative assemblages of pipe and fittings shall withstand service pressures over the temperature ranges that might be encountered in the intended application without rupture or leakage of fluids from the system. Temperatures shall be considered as follows:

Cold-water systems: 73.4°F (23°C)

Domestic hot-water systems: 180°F (82°C)

Special high-temperature, non-superheated, hot-water systems: 205°F (96°C)

Method of Evaluation for A.1.1

The present ASTM D1598[1] and D1599[2] tests for long term and short-time pressure testing used together appear sufficient for this requirement.

The apparatus and procedure for long-term testing are as specified in ASTM D2837[3] except that the test specimen shall consist of two equal lengths of pipe joined with a fitting in accordance with the recommendations of the pipe manufacturer. The evaluation shall be performed with each type of fitting that might be used to join the pipe for the application considered.

The temperature of the water within the test specimen during the test shall be as stated in the Criterion, for the application considered. The short-time burst strength for the assembly shall be as recommended by the manufacturer.

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[1] Time-to-Failure of Plastic Pipe Under Constant Internal Pressure, ASTM D1598 (ANS B72.6).

[2] Short-Time Rupture Strength of Plastic Pipe, Tubing, and Fittings, ASTM D1599 (ANS K65.53).

[3] Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials, ASTM D2837 (ANS K65.153).

Commentary on A.1.1

Piping joining solvents, cements or other joining materials must be compatible with the pipe so that cemented joints are adequately tight to preclude leakage under service conditions or representative hydrostatic/pneumatic tests. Chemical compatibility must be realized to preclude joint leakage due to poor bond, or to chemical or aging changes in the joining material or in the attached pipe, fitting, or device. The means provided for joining pipe and fittings to dissimilar materials should be such as to facilitate the maintenance of leak-free connections under conditions of variable temperature and pressure, and to facilitate disconnection or ready replacement in the future, where this might be required. The joint system should be appropriate to the particular piping material and the procedures for preparing and making the joints should be based on the manufacturer's recommendations. Product standards and industry publications provide guidance in these matters (See Appendix, Sections 8.2 and 8.3).

Whether the method of ASTM D2837 is suitable for the treatment of failure data on an assemblage of pipe and fittings has not been determined in the present study. This question should be resolved, as it could affect the practicability of the method of evaluation recommended.

A. Attribute: FUNCTIONAL ADEQUACY

A.1 Requirement: LEAK RESISTANCE

A.1.2 Criterion: Resistance to Shock Pressure

Pipe, fittings, and joints intended for use in water-distributing systems within residential buildings shall withstand a repetitive shock pressure of 150 psi (1.03M Pa) for 350,000 cycles at temperatures specified in Table A.1.2 without rupture or leakage of fluids from the system.

TABLE A.1.2

SHOCK PRESSURE TEST TEMPERATURES

Intended Application	Test Temperature
Cold Water Only	50°F (10°C)
Hot Water Only	180°F (82°C)
Hot or Cold Water	50°F (10°C) 180°F (82°C)

Method of Evaluation for A.1.2

No standard test method exists.

Commentary on A.1.2

An important basic criterion by which the ability of piping systems to withstand the impact produced by water hammer may be judged is the number of cycles of shock pressure that may occur before failure. However, the result may be dependent on the form of the pressure wave as well as on the properties of the piping material. A suitable test procedure should utilize a reproducible, representative pressure cycle with respect to amplitude, frequency, and rate of transfer of energy in the simulation of service shock pressure conditions. These parameters might be related to the properties of a piping material that determine its ability to absorb the energy at the rate produced.

In establishing the reproducible shock pressure to be used for testing, it would be important to take into account the range of waveforms produced in actual service situations.

Excessive impact loads caused by handling, installation and use can reduce the maximum static pressure or the number or magnitude of repetitive pressure shocks that the system can tolerate without failure.

Some methods that have been used in shock pressure tests of piping have been summarized.[1] Based on this work, a frequency of 2 Hz with a pulse width of 0.16 s is suggested for test purposes.

A method for shock pressure testing for acceptance of water-hammer arrestor devices has been described in ANS A112.26.1.[2] The recommendation for resistance to a repetitive 150 psi (shock plus static) pressure stems from that standard.

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[1] Laboratory Tests of Thermoplastic Piping Assemblies Subjected to Water Hammer and Intermittent Hot Water Flow. National Bureau of Standards NBSIR 77-1261 (August, 1977).

[2] Water Hammer Arrestors, ANS A112.26.1, American Society of Mechanical Engineers.

A. Attribute: FUNCTIONAL ADEQUACY

A.2 Requirement: DRAINABILITY AND HYDRAULIC CAPACITY

A.2.1 Criterion: Beam/Column Deflection and Ring Distortion

Essential functions of the piping shall not be compromised by intermittent and temporary changes in design direction or pitch, nor in cross-sectional area or shape of the piping, during exposure to representative intermittent hot water loading (140°F[1] for DWV piping and 180°F for water distribution piping for residential use) and associated pressures and thermally induced structural loads. Directional or pitch change shall not exceed arctan 0.01 (equivalent to approximately 1/8 in/ft). The difference between maximum and minimum diameters at any cross section shall not exceed 10% during the exposure to hot water.

Method of Evaluation for A.2.1

No standard test method exists.

Commentary on A.2.1

Adequate hydraulic capacity is generally considered essential for the purposes of the basic functional requirements. Satisfaction of this requirement is facilitated by materials and designs that provide for the minimization of intermittent changes in cross sectional area and shape, and for the minimization of lateral movement or deflection under ordinary service conditions.

[1] Frequent exposure of DWV piping to water temperatures in excess of 60°C (140°F) for any extended period of time seems unlikely. However, because water heaters may sometimes be shipped with thermostats set at a higher temperature and because new dishwashers with internal heaters may discharge approximately two gallons of water at about 82°C (180°F) over a short time, any further development work on this test should include a review of representative exposure temperatures. Possibly a temperature of 68°C (155°F) would be realistic for test purposes.

Design hydraulic carrying capacities, pneumatic pressure control and self-scouring capability are dependent on the continuous maintenance of design pitch in "horizontal" lines and of initial cross-sectional area and shape in both horizontal and vertical lines. Pitch changes of more than arctan 0.01 in horizontal lines can adversely affect self-scouring capability and hydraulic-pneumatic system functions, and directional changes of more than arctan 0.01 in either vertical or horizontal lines can adversely affect acoustic performance. Diametral differences greater than 10% may indicate structural instability of pipe and may adversely affect functional performance of the system, at least for horizontal lines. A reasonable limit for cross-sectional area change needs to be established. A test procedure should provide for a reproducible, representative loading cycle, applied to a representative assembly of pipe, fittings, supports and attachments. The minimum level of performance established should be consistent with the essential requirements for fluid-transport capacity of the piping system, and consistent with the general capability of the trade to provide the corresponding necessary precision in installation detail. Some of the test procedures that have been utilized have been summarized.[2]

The test employed should be designed for extended application to serve the needs of A.1.1. Probably the purposes of A.2.1 would be served by measurements made during the first 100 cycles of a suitable cyclic hot water exposure test.

[2] Laboratory Tests of Thermoplastic Piping Assemblies Subjected to Water Hammer and Intermittent Hot-Water Flow. National Bureau of Standards NBSIR 77-1261 (August, 1977).

A. Attribute: FUNCTIONAL ADEQUACY

A.2 Requirement: DRAINABILITY AND HYDRAULIC CAPACITY

A.2.2 Criterion: Continuity and Smoothness of Interior Surfaces

Piping shall facilitate efficiency and continuity of hydraulic functional operation, as follows:

1. The interior surfaces of pipe and fittings shall be smooth and essentially free of burrs, ledges, shoulders or other surface discontinuities.
2. Materials and techniques for making joints shall not effectively reduce the internal cross-sectional area of the piping nor introduce significant discontinuities in the interior surface.

Method of Evaluation for A.2.2

No standard test method exists.

Commentary on A.2.2

Excessive roughness causes energy loss and reduction of hydraulic capacity in piping and may contribute to the buildup of deposits in both water supply piping and drainage piping.

Pipe, fittings and joints should be manufactured and installed so as to facilitate efficiency and continuity of hydraulic functional operation. Abrupt, sharp-radius changes in direction should be avoided by the use of hydraulically efficient, smooth-turn fittings. Drainage piping should not be reduced in cross-sectional area in the normal direction of flow (certain standard methods for connecting 4 in (100 mm) water closet branches to 3 in (75 mm) soil stacks excepted). Restrictions, abrupt enlargements or discontinuities at pipe joints can reduce hydraulic capacity, contribute to fouling and stoppage, adversely affect cleanability, and contribute to corrosion.

Standard test methods for hydraulic resistance or for surface discontinuity and relief are needed, that would address the parameters indicated above.

Laboratory test procedures should provide for a reproducible, representative fluid load, applied to a representative assembly of pipe and fittings. The measure of overall resistance to fluid flow might be a roughness factor or a head loss as determined by a procedure that is consistent with the generally accepted "rational" pipe flow formula.[1] The measure of surface relief and discountinuity might be based further on the adaptation of a method that has been used for determining the surface profiles of abraded surfaces of porcelain enameled and fiberglass-reinforced polyester sanitary plumbing fixtures.[2]

Useful guidance for designers and installers in attaining minimum hydraulic resistance and in maintaining surface continuity has been provided in a number of industry publications (See Appendix, Section 8.3).

Flow velocity, water composition and service temperature should be considered in the selection of piping materials and in the estimation of hydraulic resistance in the service environment. Further data and/or analysis are needed on these effects, to facilitate rational and realistic decisions concerning design, specification and acceptance where innovative piping materials are being considered.

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[1] Handbook of Hydraulics, E. F. Brater and Horace King, McGraw-Hill, 1976.

[2] Investigation of Performance Characteristics for Sanitary Plumbing Fixtures. National Bureau of Standards BSS 22 (1970).

A. Attribute: FUNCTIONAL ADEQUACY

A.3 Requirement: ACOUSTICAL ACCEPTABILITY

A.3.1 Criterion: Noise Reduction Between Living Units, Through Interdwelling Walls Containing Piping

The design and installation of the plumbing system, taken together with that of the wall, chase, or partition in which the piping is enclosed, shall be such that the noise reduction set forth in Table A.3.1 can be attained between living units, and between public space or service areas (e.g., corridors or mechanical equipment rooms) and a living unit.

The Sound Transmission Class (STC) rating of interdwelling walls, determined by documentation or laboratory measurement, shall be 5 units greater than the Noise Isolation Class (NIC) values given in Table A.3.1.

Method of Evaluation for A.3.1

Evaluation of design drawings and computation.
Field inspection and documentation during construction.
The NIC ratings shall be determined by tests of prototype or field units.

Test Methods

Appendix A1 of ASTM E336, "Standard Recommended Practice for Measurement of Airborne Sound Insulation in Buildings" (for NIC).
ASTM E90, "Standard Recommended Practice for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions (for STC).
ASTM E413, "Standard Classification for Determination of Sound Transmission Class." (This is used for both NIC and STC determination).

Commentary on A.3.1

The NIC rating is based upon noise reduction, which is a measure of the sound isolation between two enclosed spaces, the source space and the receiving space, and is not necessarily a function of the dividing partition alone since it is affected by any flanking paths.

TABLE A.3.1

Minimum Noise Isolation of Interdwelling Walls and Partitions

LOCATION OF PARTITION	NOISE ISOLATION CLASS (NIC)
Living unit to living unit corridor[1] or public space of average noise[2]	40
Living unit to public space and service areas of high noise[3]	45

[1] These values assume floors in corridors are carpeted; otherwise increase NIC by 5.

[2] Public space of average noise includes lobbies, storage rooms, stairways, etc.

[3] Areas of high noise include boiler rooms, mechanical equipment rooms, elevator shafts, laundries, trash or incinerator shafts, garages, and most commercial uses. Increase NIC by 5 when adjacent to mechanical equipment which operates at high noise levels.

The STC rating is a laboratory measure of the best sound isolation that could be obtained with a given partition design. It specifically excludes the effects of any flanking paths, and is usually somewhat better than field performance. When the STC rating cannot be justified by published data for similar partitions or by computation using appropriate analysis, laboratory measurements shall be made. Results should be obtained prior to construction.

As a design guide, STC-type measurements of completed assemblies (with all plumbing installed) may be made in the laboratory to help predict attainment of the required field performance.

A. Attribute: FUNCTIONAL ADEQUACY

A.3 Requirement: ACOUSTICAL ACCEPTABILITY

A.3.2 Criterion: Noise Reduction Between Living Units, Through Interdwelling Floor-Ceilings Containing Piping

The design and installation of the plumbing system, taken together with that of the chase or floor-ceiling in which the piping is enclosed, shall be such that the noise reduction set forth in Table A.3.2 can be attained between living units, and between public space or service areas (e.g., corridors or mechanical equipment rooms) and a living unit.

The STC and IIC ratings of interdwelling floor-ceiling assemblies, determined by documentation or laboratory measurement, shall be 5 units greater than the NIC and field IIC values given in Table A.3.2.

Method of Evaluation for A.3.2

Evaluation of design drawings and computation.
Field inspection and documentation during construction.
The NIC and field IIC ratings shall be determined by tests of prototype or field units.

Test Methods

Appendix A1 of ASTM E336, "Standard Recommended Practice for Measurement of Airborne Sound Insulation in Buildings" (for NIC).
ASTM E90, "Standard Recommended Practice for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions (for STC).
ASTM E413, "Standard Classification for Determination of Sound Transmission Class" (This is used for both NIC and STC determination).
ASTM E942, "Tentative Method of Laboratory Measurement of Impact Sound Transmission through Floor-Ceiling Assemblies Using the Tapping Machine." (This is used for both laboratory and field measurement).

TABLE A.3.2

Minimum Noise Isolation and Impact Insulation of Interdwelling Floor-Ceiling Assemblies

LOCATION OF FLOOR-CEILING	NIC	FIELD IMPACT INSULATION CLASS (FIELD IIC)
Floor-ceiling separating living units from other living units corridors,[1] public space[2] or service areas of average noise[3,4]	40	40
Floor-ceiling separating living units from public space and service areas (high noise)[5] including corridor floors over living units[4]	45	45

1 These values assume floors in corridors are carpeted; otherwise increase NIC and IIC by 5.

2 Does not apply to field impact insulation class (IIC) of floor above storage rooms where noise from living units would not be objectionable.

3 Public space of average noise includes lobbies, storage rooms, stairways, etc.

4 The impact insulation requirements may be relaxed where equivalent performance is achieved, e.g., where heating, ventilating, and air-conditioning (HVAC) equipment is mounted with effective vibration isolation.

5 Areas of high noise include boiler rooms, mechanical equipment rooms, elevator shafts, laundries, incinerator shafts, garages and most commercial uses. Increase NIC by 5 when adjacent to mechanical equipment which operates at high noise levels.

Commentary on A.3.2

The NIC rating is based upon noise reduction, which is a measure of the sound isolation between two enclosed spaces, the source space and the receiving space, and is not necessarily a function of the dividing partition alone since it is affected by any flanking paths.

The STC rating is a laboratory measure of the best sound isolation that could be obtained with a given partition design. It specifically excludes the effects of any flanking paths, and is usually somewhat better than field performance. When the STC rating cannot be justified by published data for similar partitions or by computation using appropriate analysis, laboratory measurements shall be made. Results should be obtained prior to construction.

As a design guide, STC-type measurements of completed assemblies (with all plumbing installed) may be made in the laboratory to help predict attainment of the required field performance.

A. Attribute: FUNCTIONAL ADEQUACY

A.3 Requirement: ACOUSTICAL ACCEPTABILITY

A.3.3 Criterion: Noise Reduction Between Spaces Within a Living Unit, Through Walls and Partitions Containing Piping

The design and installation of the plumbing system, taken together with that of the wall, chase, or partition in which the piping is enclosed, shall be such that a noise reduction of at least NIC 28 can be attained within a living unit between spaces where noise insulation is intended.

As a design guide, the STC rating of the walls, determined by documentation or laboratory measurement, should be at least 7 units greater than the NIC value given.

Method of Evaluation for A.3.3

The NIC ratings shall be determined by tests of prototype or field units.

Test Methods

Appendix Al of ASTM E336, "Standard Recommended Practice for Measurement of Airborne Sound Insulation in Buildings" (for NIC).
ASTM E90, "Standard Recommended Practice for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions" (for STC).
ASTM E413, "Standard Classification for Determination of Sound Transmission Class." (This is used for both NIC and STC determination).

Commentary on A.3.3

The NIC rating is based upon noise reduction, which is a measure of the sound isolation between two enclosed spaces, the source space and the receiving space, and is not necessarily a function of the dividing partition alone since it is affected by any flanking paths.

The STC rating is a laboratory measure of the best sound isolation that could be obtained with a given partition design. It specifically excludes the effects of any flanking paths, and is usually somewhat better than field performance.

A. Attribute: FUNCTIONAL ADEQUACY

A.3 Requirement: ACOUSTICAL ACCEPTABILITY

A.3.4 Criterion: Noise Reduction Between Spaces Within A Living Unit, Through Floor-Ceilings Containing Piping

The design and installation of the plumbing system, taken together with that of the chase or floor-ceiling in which the piping is enclosed, shall be such that a noise reduction of at least NIC 28 and field IIC 28 can be attained within a living unit between spaces where noise insulation is intended.

As a design guide, the STC and IIC ratings of the floor-ceiling assemblies determined by documentation or laboratory measurements should be at least 7 units greater than the NIC and field IIC values given.

Method of Evaluation for A.3.4

The NIC and field IIC ratings shall be determined by tests of prototype or field units.

Test Methods

Appendix A1 of ASTM E336, "Standard Recommended Practice for Measurement of Airborne Sound Insulation in Buildings" (for NIC).

ASTM E90, "Standard Recommended Practice for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions" (For STC).

ASTM E413, "Standard Classification for Determination of Sound Transmission Class." (This is used for both NIC and STC determination).

ASTM E492, "Tentative Method of Laboratory Measurement of Impact Sound Transmission Through Floor-Ceiling Assemblies Using the Tapping Machine." This is used for both laboratory and field measurements.

A. Attribute: FUNCTIONAL ADEQUACY

A.3 Requirement: ACOUSTICAL ACCEPTABILITY

A.3.5 Criterion: Noise Level in Interior Spaces During Operation of Plumbing System

Noise in interior spaces shall be kept below a level which will cause discomfort or annoyance to the occupants. Each plumbing system element shall perform its intended function without excessive noise generation or compromise of the acoustical performance of other building elements. The design and installation of the plumbing system, taken together with that of the plumbing wall, chase, floor-ceiling or partition in which the piping is enclosed, shall be such that the A-weighted-sound levels in interior living spaces shall not exceed 45 dB during the imposition of typical hydraulic loads (drainage and water supply).

Method of Evaluation for A.3.5

Measurement of sound pressure levels in living spaces of unoccupied prototypes after completion with all plumbing systems installed and in operation.

Test Methods

ANS S1.13 "Standard Methods for Measurement of Sound Pressure Levels." (Sound levels resulting from interior building sources shall be read on a meter with fast-response characteristic and weighted on the A-scale as defined for Sound Level Meters).

5.3 CRITERIA FOR HEALTH AND LIFE SAFETY

This group of criteria is concerned with the type of performance that is required to provide service without harmful effects on user health or safety, insofar as this may depend on the properties of the materials of which the piping system is comprised (See Figure 6 and Table 3). An example is resistance to the impartation of toxic substances to potable water. Another example is resistance to fire spread through wall assemblies containing piping systems.

Again, as with the functional criteria, performance of the piping from the standpoint of health and safety can be influenced by the characteristics of the interface between pipes and fittings, and between the piping and the building materials. Therefore, the criteria must address installed assemblages rather than simply pipes and fittings individually.

B. Attribute: ADEQUACY FOR HEALTH/SAFETY

B.1 Requirement: TOXICOLOGICAL ACCEPTABILITY

B.1.1 Criterion: Elution of Toxic Substances

Materials used for potable water service and distribution systems shall not contribute to a health hazard through contamination of the potable water. The purity of the potable water at the points of use shall meet the levels in the Public Health Service Drinking Water Standards[1] as amended by the National Interim Primary Drinking Water Regulations.[2] Inorganic chemical contaminants shall not exceed the levels set forth in Table B.1.1.

Method of Evaluation for B.1.1

The test procedure for extraction of inorganic chemicals shall be as promulgated by the National Sanitation Foundation[3,4] and recommended by a task group of the Federal Construction Council - Building Research Advisory Board.[5] All innovative piping materials used in the potable water service and distribution systems shall be approved as toxicologically

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[1] Public Health Service Drinking Water Standards - 1962, PHS Publication No. 956. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

[2] National Interim Primary Drinking Water Regulations, Environmental Protection Agency Water Programs, Subchapter D, Part 141, Federal Register, Volume 40, No. 248, December 24, 1975. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

[3] A Study of Plastic Pipe for Potable Water Supplies, W. D. Tiedman and N. A. Milone, June 1955, National Sanitation Foundation, P. O. Box 1468, 2355 West Stadium Blvd., Ann Arbor, Michigan 48106.

[4] National Sanitation Foundation Standard No. 14. "Thermoplastic Materials - Pipe, Fittings, Valves, Jointing Materials", October 1965. National Sanitation Foundation, P. O. Box 1468, 2355 West Stadium Blvd., Ann Arbor, Michigan 48106.

[5] Thermoplastic Piping for Potable Water Distribution Systems, BRAB/FCC Technical Report No. 61, 1971, National Academy of Sciences - National Research Council, 2101 Constitution Avenue, Washington, D.C. 20418.

TABLE B.1.1

Maximum Contaminant Levels

Inorganic Chemicals:

Contaminant	Level, milligrams per liter
Arsenic	0.05
Barium	1.
Cadmium	0.010
Chromium	0.05
Lead	0.05
Mercury	0.002
Nitrate (as N)	10.
Selenium	0.01
Silver	0.05

suitable for the purpose by a generally recognized testing/evaluating agency. One such agency is the National Sanitation Foundation Testing Laboratory.

Commentary on B.1.1

The test recommended appears adequate for inorganic chemical contaminants. However, no test has been developed for possible contaminants or other effects from potential slime growth on the interior of the pipe.

Generally, lead pipe and fittings shall not be used to convey potable water, nor shall pipe and fittings be used in the conveyance of potable water that are manufactured with a process that leaves a residue of lead compound on the interior surface of the piping, nor shall the materials as installed contribute to deleterious elution of lead compounds into the potable water.

In the installation or major repairs of potable water systems, sterilization shall be accomplished in accordance with generally accepted practice, and piping which has previously been used for any purpose other than for conveying potable water shall not be used for conveying potable water[6,7].

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[6] The Model Codes are:

Basic Plumbing Code (BPC), Building Officials and Code Administrators International, Inc. (BOCA), 1313 E. 60 Street, Chicago, Illinois 60637.

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

Standard Plumbing Code (SPC), Southern Building Code Congress International, Inc. (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, CA 90032.

[7] AWWA Standard for Disinfecting Water Mains, AWWA C101, American Water Works Association, 6666 W. Quincy Ave., Denver, Colo. 80235

B. Attribute: <u>ADEQUACY FOR HEALTH/SAFETY</u>

B.2 Requirement: <u>FIRE SAFETY</u>

B.2.1 Criterion: <u>Fire Spread</u>

The drain-waste-vent (DWV) system, as designed and installed, including exposed piping and piping within walls, chases, and floor-ceiling assemblies, shall not compromise the fire endurance ratings of such walls, chases, and floor-ceiling assemblies as set forth in Table B.2.1.

TABLE B.2.1 1/

Minimum Fire Resistance Ratings in Hours by Types of Construction (1)

ELEMENTS OF CONSTRUCTION	TYPE 1	TYPE 2 2a	TYPE 2 2b	TYPE 3 3a(2)	TYPE 3 3b	TYPE 4
EXTERIOR WALLS						
Bearing						
Under 30 ft separation	2	2	1	2	2	1
30 ft and over separation	2	2	3/4	2	1	3/4
Non-Bearing						
Under 10 ft separation	2	1	1	2	2	1
10 ft to 30 ft separation	1	1	3/4	1	1	3/4
Over 30 ft separation	0	0	0	0	0	0
INTERIOR WALLS & PARTITIONS						
Fire, and lot-line walls	2	2	2	2	2	2
Bearing	2	1	1	2	1	1
Non-bearing	NC	NC	NC	C	C	C
Exit enclosure of stairways, elevator shafts, etc. (3)	2	2	1	2	1	1
Partitions separating living units and enclosing public corridors	1	1	1	1	1	1
FLOOR CONSTRUCTION (6)	2	1	1	1	1	1
WALLS, FLOORS AND CEILINGS						
1. Of lobbies and corridors between exit stairways and exterior	2	2	1	2	1	1
2. Separating commercial from residential	2	2	2	2NC	2NC	2
3. Enclosing service spaces	2	2	2	2	2	2
4. Enclosing tenant general storage area	1	1	1	1	1	1
5. Separating garage from residential						
For 1 to 4 cars	1	1	1	1	1	1
For more than 4 cars	2	2	2	2	2	2
SHAFT ENCLOSURES	2	2	1	1	1	1
CONSTRUCTION ENCLOSING BOILER, HEATER OR INCINERATOR ROOMS, FUEL STORAGE AREAS AND TRASH CHUTES (7)	2	2	2	2	2	2

1/ These fire ratings are derived from the HUD Minimum Property Standards No. 4910.1 for Multi-family housing.

Notes for Table B.2.1

(1) Abreviations:

O designates that no specific fire resistance rating is required.
L.U. - Living Unit
NC designates noncombustible construction, but no specific fire resistance rating is required.
C designates that the structural members of the construction may be of combustible materials, but no specific fire resistance rating is required.

Types of Construction:

All residential buildings shall be classified into one of the following construction types:

Type 1 - Fire Resistive
Type 2 - Noncombustible
    Subtypes: 2a and 2b
Type 3 - Exterior Protected
    Subtypes: 3a and 3b
Type 4 - Wood Frame

(2) In Type 3a construction the corridor walls, floors and ceilings, partitions enclosing vertical openings, stairways, columns and beams shall be 2-hr. noncombustible for structure of 3 or more stories, and 1-hr. noncombustible for 1 or 2 stories.

(3) In buildings of Types 1, 2a and 3a construction, not more than 3 stories in height, and having not more than 12 living units within a fire division, exit enclosures may have fire resistive rating of one hour.

(4) Roof construction with ventilated attic need only have ceiling assemblies with a finish rating of at least 20 minutes.

(5) Service spaces are paint, carpentry or maintenance shops and other spaces where flammable materials are stored.

(6) Floor construction within a two story living unit may have a 1/3 hr. fire resistance rating, where limited to one living unit in building height, and walls separating units are at least 1 1/2 hr. rating.

(7) Individual living unit heater rooms not included in this requirement.

Method of Evaluation for B.2.1

ASTM E119 Fire Endurance Test[2].

Commentary

Fire resistance rated walls, chases and floor-ceiling assemblies which are to have DWV systems within or penetrating their construction should be subjected to the same testing criterion as the rated assembly without plumbing. ASTM E119 is a generally accepted test for rating the fire resistance of structural components. Therefore, a test of the assembly with the DWV system installed as intended for the field application is recommended to assure compliance with the fire resistance requirements of Criterion B.2.1. Traps extending from the wall should be filled with water as representative of a field installation. The ASTM E119 fire endurance test puts limits on the temperature rise of the unexposed side of the wall (139°C average temperature rise over the surface and 181°C rise at any point), and prohibits the passage of flames and hot gases sufficient to ignite cotton padding. Trap arms, traps and pipes penetrating the wall are excluded from the temperature rise limitation since they are not part of the wall surface specified in ASTM E119.

[2] Standard Methods of Fire Tests of Building Construction and Materials. ASTM Designation E119.

B. Attribute: ADEQUACY FOR HEALTH/SAFETY

B.2 Requirement: FIRE SAFETY

B.2.2 Criterion: Spread of Smoke and Toxic Gases

The inclusion of plumbing systems and their components as part of a wall, chase or floor-ceiling assembly, shall not cause the spread of excessive smoke and toxic gases to the unexposed side of the assembly. Generally accepted quantative limits for smoke and toxic gases for the purpose of this criterion have not been established.

Method of Evaluation for B.2.2

No standard test method exists.

Commentary

It is recommended that a standard test method be developed based on the ASTM E119 test[1], but which in addition would simulate representative air circulation conditions and would include suitable methods of sampling and measuring the concentrations of smoke and toxic gases transferred to the unexposed side of the assembly during the fire test. Further research is needed to provide a basis for acceptable limits as well as for standard test procedures and methods of measurement.

It is recommended that no combustible piping be placed within ventilation shafts or chases vented to the inside of the building, without the installation of adequate accessible protective sprinklers.

[1] Standard Method of Fire Tests of Building Construction and Materials. ASTM Designation E119.

B. Attribute: ADEQUACY FOR HEALTH/SAFETY

B.2 Requirement: FIRE SAFETY

B.2.3 Criterion: Flame Spread

The surface flame spread of exposed piping shall not be in excess of the limits set forth in Table B.2.3.

TABLE B.2.3

FLAME SPREAD RATING LIMITATIONS FOR EXPOSED INTERIOR PIPING (1)(2)

Location Within Building	Surface Flame Spread Rating-Maximum Range
Enclosed Stairways & Other Vertical Openings	0-25
Corridors or Hallways & Other Exits	0-75
Within Living Unit (3)	0-200
Public Rooms & Entrance Spaces	0-75
Lobbies & Corridors Between Exit Stairway & Exterior	0-25
Service Rooms, Enclosing Heat Producing or Other Mechanical Equipment, and all other Fire Hazardous Areas	0-25

Notes

(1) Plumbing fixtures may be excluded in the determination of flame-spread limitations for rooms or other spaces.

These flame spread ratings are comparable to those for exposed building materials in the same locations as given by the HUD Minimum Property Standards.

(2) Where automatic sprinkler protection is appropriately provided, the flame spread ratings may be increased in the following amounts; 0-25 to 0-75 and 0-75 to 0-200.

(3) Flame spread rating in housing for the elderly = 0-75.

Method of Evaluation for B.2.3

ASTM E84[1] or ASTM E162[2] tests for surface burning characteristics or surface flammability.

Commentary

The flame spread rating is an accepted method for expressing surface burning characteristics of building materials. The criterion is designed to limit the potential rapid spread of fire within rooms or other open spaces along horizontal or vertical runs of exposed piping that might be subject to significant surface flame spread.

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1 Standard Method of Test for Surface Burning Characteristics of Building Materials. ASTM Designation E84.

2 Standard Method of Test for Surface Flammability of Materials Using a Radiant Heat Energy Source. ASTM Designation E162.

5.4 CRITERIA FOR DURABILITY AND MAINTAINABILITY

This group of criteria describes measures for evaluating capability for continued, functionally adequate service for a reasonable length of time without excessive maintenance. If these criteria are adequate and are applied, then continued performance is assured for the functional criteria (Section 5.2). It is assumed that degradation over time is not more critical to health and safety (Section 5.3) than to function. The criteria for durability and maintainability are concerned primarily with those properties or characteristics that might be subject to change over a period of service; for example, strength, dimensions, flexibility, etc. (See Figure 6 and Table 3, pages 52 and 54, respectively).

The purpose of these criteria is to facilitate the prediction of long term performance potential by the use of short-term laboratory tests. Correlation is needed between the results of such tests and the results of long-term service exposure tests or laboratory tests simulating service exposure (See A.1.1, A.1.2, A.2.1 and C.1.1).

C. Attribute: ADEQUACY FOR DURABILITY/MAINTAINABILITY

C.1 Requirement: RETENTION OF PROPERTIES FOR ESSENTIAL FUNCTIONAL PERFORMANCE

C.1.1 Criterion: Long-Term Stability of Dimensions and Strength

The planned life expectancy of the piping system as installed shall be attainable without compromise of the essential functional performance of the system from degradation of the important dimensional and structural properties of the piping materials, with representative intermittent exposures to the expected extreme conditions of hot water and aggressive wastes, and to the expected maximum pressures and other structural loads. The following criteria are applicable:

(a) Dimensional Change

Exposure to 100,00 cycles of a suitable hot-water exposure test shall not cause the maximum angular deflection of pipes to exceed arctan 0.01, the diametral difference to exceed 10%, and the creep or permanent linear dimensional change to exceed 0.5%.

(b) Strength Reduction

Exposure to 100,000 cycles of a suitable hot-water exposure test shall not cause the impact resistance, the ring-deflection strength and the beam strength to decrease by more than 25%. Further, the exposure shall not cause the burst strength and leak resistance to be reduced below the levels required by Criteria A.1.1 and A.1.2.

Method of Evaluation for C.1.1

Although no standard all-inclusive performance evaluation methodology has yet been established (see Commentary), the following test methods should be used for determination of important individual performance characteristics or related properties:

(a) Glass Transition Temperature[1]

See Table C.1.1

[1] This and other terms are defined in Standard Definitions of Terms Relating to Plastics, ASTM D883.

(b) Hardness Temperature Coefficient

See Table C.1.1

(c) Heat Deformation and Permanent Set

See Table C.1.1

(d) Burst Strength Under Cyclic Pressure

See Table C.1.1

(e) Lateral Deflection

See Table C.1.1

A discussion of the applicable test methods is provided in the Commentary.

Commentary on C.1.1

Evaluations of innovative piping materials should take into account the possible adverse effects of extreme thermal and structural loads, piping system installation details, and representative conditions of use. Dimensional changes which may occur and the probable extremes of thermal and structural loads should not cause significant degradation of any essential aspect of functional performance including self-scouring capability, drainability, hydraulic capacity, freedom from leaks, and structural reliability of supports and attachments. Examples of environmental factors which should be considered are hot water, wood shrinkage and soil and building settlement. Permanent dimensional changes and changes in stress distributions resulting from such factors should not be sufficient to produce damaging stresses on joints, supports and attachments; excessive distortion of cross-section or excessive lateral deflection; separation of joints and expansion fittings, etc.

Depending on the duration and frequency of intermittent exposure to hot water, pipe diameter and wall thickness, distance from the source, and other factors, the temperatures within the piping material in the service environment are likely to be appreciably less than those at the source (water heater). Measurement[2,3] of glass transition temperatures for PVC, ABS, CPVC, and PB yielded values ranging from a low of 79°C (174°F) for PVC to a high of 123°C (253°F) for CPVC. Temperatures in excess of 65°C (140°F) in the the piping material seem unlikely in most residential plumbing applications. However, some new dishwashers can discharge small quantities of internally heated water into DWV piping at temperatures approaching 82°C (180°F) and some water heater thermostats are currently shipped set at 155°F. Where such higher temperatures are anticipated in the piping material, CPVC, PB or other heat-resistant material should be used. Probably there should be little concern about using ABS, PVC, CPVC or PB (having formulations identical to those examined in this study) in residential plumbing insofar as glass transition is concerned, when installed and used in accordance with generally accepted good practice. However, for future materials, this measure should be considered for evaluation purposes.

A number of ASTM tests of properties which may relate to functional performance capability are identified in Table C.1.1 and in Table 5 of the Appendix. These should be evaluated for usefulness in completing the development of the performance tests needed for C.1.1.

There are several tests of individual properties which can be used to indicate possible deficiencies in the ability of a piping system to provide essential long-term functional performance. Comments on some of these recommended evaluation tests are given below:

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[2] Investigation of Procedures for Determination of Thermal Performance Characteritsics of Plastic Piping Used in Housing. National Bureau of Standards NBSIR 74-610 (November 1974).

[3] Thermal Properties of Selected Plastic Piping Used in Housing. National Bureau of Standards NBSIR 74-629 (April 1975).

Glass transition. For a thermoplastic pipe, the glass transition temperature must be above the maximum service temperature (actual temperature in the piping material) if possible excessive permanent dimensional changes due to relaxation of internal stresses in the plastic piping components produced in the manufacture of pipe and fittings are to be prevented. The recommended test involves the measurement of the displacement of a loaded probe resting on a specimen, as a function of temperature, time and load (See Table C.1.1).

Heat deformation and permanent set. A short, simple test is needed to indicate the magnitude of the permanent deformation (dimensional change) that may be expected from exposure to heat at temperatures near the expected maximum pipe temperature in service. It appears that a simple oven test made with relatively short lengths of pipe or with fittings, not structurally loaded, provides a realistic measure of the possible deformation. Measurements[3] in 120 hour oven tests (See Table C.1.1) with PVC and ABS at 77°C (171°F) produced essentially no length change in ABS, and about -1% length change in PVC. In residential plumbing applications, a temperature as high as 77°C within the piping material seems highly unlikely because of the typical intermittent, short-duration exposure pattern and because of the cooling of the hot water in the distributing pipes and drain lines. Since typical maximum pipe temperatures in drainage systems in residential use are likely to be appreciably less than 77°C, heat deformation of PVC or ABS should not be a problem in residential DWV usage.

Creep[1]. Small dimensional changes in piping materials can be accomodated by design and installation, but excessive changes, whether intermittent or permanent, can lead to rupture and leaking, drainability problems, acoustical problems, etc. Under some conditions, permanent dimensional changes can occur through long-term creep under forces of structural or thermal orgin. The BRAB test S-3 Concentrated Load Test[4] measures creep under externally imposed structural loads,

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[1] Ibid

[3] Ibid

[4] Thermoplastic Piping for Potable Water Distribution Systems, F.C.C. Technical Report No. 61, NAS/NRC (1971).

TABLE C.1.1

SOME TESTS OF PROPERTIES OF PIPING MATERIALS THAT MAY FACILITATE EVALUATION OF CAPABILITY TO PROVIDE ESSENTIAL LONG-TERM FUNCTIONAL PERFORMANCE
(See Table 5-Appendix for additional tests)

PROPERTY ASSOCIATED WITH LONGEVITY IF ESSENTIAL FUNCTION	RELEVANT CRITERIA	TEST USED IN NBS STUDY: BRIEF DESCRIPTION	TEST USED IN NBS STUDY: REFERENCE
Glass transition temperature	Resistance to Sustained Pressure Resistance to Shock Pressure	The displacement of a loaded probe resting on a specimen is determined as a function of temperature, time and load. The temperature is raised slowly at a specified rate. Glass transition temperature, residual stress indicator and coefficient of linear expansion are calculated from the curves showing probe displacement as a function of temperature.	NBSIR 74-610 2/ and NBSIR 74-629 3/
Hardness temperature	Resistance to Shock Pressure	The penetration of the specimen by an indentor of specified shape and mass is measured at several temperatures.	NBSIR 74-610 2/ NBSIR 74-629 3/ and ASTM D2240 5/
Heat deformation and permanent set	Lateral Deflection and Ring Distortion	Length change (measured at room temperature) or pipe samples is determined after exposure to a temperature of 77°C for 1, 2 and 120 hrs. Length change is calculated as a percentage of the initial length	NBSIR 74-610 2/ and NBSIR 74-629 3/

2/ Ibid
3/ Ibid
5/ Indentation Hardness of Rubber and Plastics by Means of a Durometer, ASTM D2240.

TABLE C.1.1 (continued)

SOME TESTS OF PROPERTIES OF PIPING MATERIALS THAT MAY FACILITATE EVALUATION OF CAPABILITY TO PROVIDE ESSENTIAL LONG-TERM FUNCTIONAL PERFORMANCE
(See Table 5-Appendix for additional tests)

PROPERTY ASSOCIATED WITH LONGEVITY OF ESSENTIAL FUNCTION	RELEVANT CRITERIA	TEST USED IN NBS STUDY	
		BRIEF DESCRIPTION	REFERENCE
Burst strength under cyclic pressure	Resistance to Shock Pressure	The leak and rupture resistance of a representative assembly of pipe and fittings is measured during exposure to 350,000 programmed cycles of pressure.	NBSIR 77-1261 6/
Lateral deflection	Lateral Deflection and Ring Distortion	The lateral deflection of a representative vertical or horizontal assembly of pipe and fittings subjected to representative intermittent exposure to hot water is measured during many 7/ cycles of exposure.	NBSIR 77-1261 6/

6/ Laboratory tests of Thermoplastic Piping Assemblies Subjected to Water Hammer and Intermittent Hot Water Flow. National Bureau of Standards NBSIR 77-1261 (August, 1977)

7/ NBS test was terminated prematurely. See text for recommended numbers of cycles.

but the length of this test (10,000 hours) is a disadvantage. Tests made for heat deformation[3] and hot water effects[6] of PVC, ABS and CPVC showed no cause for concern about dimensional changes in properly installed piping under the usual conditions of residential use. No tests specifically for creep were made in this NBS study; however the test of assemblies with intermittent hot water exposure involved some structurally and thermally induced stress. The dimensional changes observed in this test were within the limitations of Criterion C.1.1.

Hardness as a function of temperature. The evaluation of piping materials for resistance to impact (e.g., shock pressure) would be facilitated if a simple relationship could be established between the temperature coefficient of hardness and the effect of temperature on the resistance of the material to failure under impact. Measurements[3] indicate there may be a correlation between these quantities.

Summary of Tests. Table C.1.1 provides a summary of the tests referred to in Section C.1.1 and relates them to specific performance criteria.

Correlation Needs. Before full reliance can be placed on the tests suggested above for evaluating the stability of dimensions and strength of piping materials, it will be necessary to establish correlations, under selected conditions, between the performance measured in these tests and that in full-scale tests in representative assemblies exposed to intermittent hot and/or cold water, and to shock pressure and sustained pressure.

[3] Ibid

[6] Ibid

C. Attribute: ADEQUACY FOR DURABILITY/MAINTAINABILITY

C.1 Requirement: RETENTION OF PROPERTIES FOR ESSENTIAL FUNCTIONAL PERFORMANCE

C.1.2 Criterion: Resistance to Chemical Attack and Environmental Stress Cracking

Essential functional performance of piping systems shall not be compromised through degradation of critical properties of the materials, by the most severe expected exposures to household cleaning chemicals, drain declogging chemicals, or ordinary household wastes, nor to the chemicals normally contained in potable water supplies, during the existence of representative stresses in the systems.

Method of Evaluation for C.1.2

No standard test method exists.

Commentary on C.1.2

The present widespread acceptance of several specific types of thermoplastic piping for residential plumbing and the absence of recent reports of failures due to chemical attack or environmental stress cracking, suggests that these characteristics have ceased to be of significant concern in this application of these thermoplastic piping materials. However, the following discussion is provided to illustrate the considerations that might be involved in applying the performance approach to the evaluation of future innovative piping materials.

Among the principal environmental variables affecting resistance of installed DWV piping to chemicals are: (1) concentration and composition of chemicals introduced into piping systems (2) retention period in system or component, and frequency of exposure to wastes containing chemicals (3) temperature of the liquids containing the chemical agents during the exposure period.

Stress concentration during exposure to certain chemicals may contribute to environmental stress cracking of some materials. Some degree of stress concentration, particularly at joints/fittings might arise from conditions such as: (a) Forced alignment of pipes and fittings during installation. (b) Building settlement, lumber shrinkage. (c) Thermal expansion/contraction and long-term dimensional changes.

In order to establish representative values for these variables in a test simulating service exposure conditions, adequate data from actual use in occupied buildings are needed. It would also be important to consider the heat-absorbing and heat-transfer properties of the piping materials in the development of such a test.

The problem of defining a suitable test for innovative materials involves defining representative waste temperature and composition, and establishing a representative exposure cycle. Such a procedure should be capable of producing results indicating satisfactory performance of materials that have been found generally acceptable through the test of service history. The test should utilize the measures of leak resistance, drainability, hydraulic capacity and stability of strength and dimensions as determinants of the adequacy of performance of representative assemblies after representative exposure.

Two chemical tests have been suggested as useful, by the Federal Construction Council of the Building Research Advisory Board.[1,2] One of these (Test C-1 Chemical Test) was for potable water pipe and fittings. This test utilized an ASTM procedure for determination of resistance to bursting[3].

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[1] Thermoplastic Piping for Potable Water Distribution Systems. BRAB/FCC Technical Report No. 61 (1971). National Academy of Sciences - National Research Council.

[2] Rigid Thermoplastic Pipe and Fittings for Residential Drain-Waste and Vent Systems. BRAB/FCC Technical Report No. 52 (1966). National Academy of Sciences - National Research Council.

[3] Standard Method of Test for Short-Time Rupture Strength of Plastic Pipe, Tubing and Fittings, ASTM D1599.

The other BRAB test (Chemical Resistance) was for DWV piping. This test utilized ASTM D790[4] for determination of flexural strength and modulus of elasticity. The ASTM tests were suggested for determination of changes in the indicated properties resulting from specified chemical exposures for relatively short periods of time.

The principal deficiencies of the tests (as performance evaluation methods) are (1) the key exposure conditions (concentration, composition, duration of continuous exposure, temperature, stress level and flushing) may not be adequately representative, and (2) it is not known whether the durations of exposure in the tests will produce a suitable simulation of the cumulative effects of many short-time exposures over a period of years in the service environment. Further, the tests used for detecting changes in characteristics do not evaluate dimensional stability, and in the case of DWV piping, do not address possible changes in joints nor in leak resistance of piping assemblies. None of the tests reviewed involved testing under stress levels established as representative of the service environment.

[4] Test for Flexural Properties of Plastics, ASTM D790.

C. Attribute: <u>ADEQUACY FOR DURABILITY/MAINTAINABILITY</u>

C.1 Requirement: <u>RETENTION OF PROPERTIES FOR ESSENTIAL FUNCTIONAL CAPABILITY</u>

C.1.3 Criterion: <u>Resistance to Abrasion and Cutting</u>

Materials used for DWV piping shall provide resistance to abrasion and cutting adequate to permit the use of all likely mechanical pipe-cleaning procedures without adverse effects on the essential functional performance of the system.

<u>Method of Evaluation for C.1.2</u>

No standard test method exists.

<u>Commentary on C.1.3</u>

Appropriate fittings should be installed so as to facilitate the use of commercial drain cleaning tools without excessive abrasion or cutting of the interior surfaces of the piping. Tools that minimize abrasion and cutting of piping are commercially available, and should be specified for cleaning.

Alternative approaches to drain cleaning, e.g., the use of compressed air or hydraulic jets, could further reduce the danger of inadvertent internal abrasion and cutting.

System designs using fittings, materials and configurations conforming to current generally accepted good practice for drainage should not be subject to significant damage from abrasion or cutting from cleaning tools generally recognized by the trade as appropriate to the particular cleaning task and piping material.

6. CONCLUSIONS

6.1 STATUS AND BENEFITS OF PERFORMANCE EVALUATION METHODOLOGY FOR PIPING MATERIALS IN RESIDENTIAL PLUMBING

(a) Essential qualitative performance requirements are recommended herein, and a number of specific parameters have been identified that could be used as quantitative measures of conformance to the requirements.

(b) Some of the characteristics of selected thermoplastics have been considered in this study to illustrate the development of performance evaluation methodology for piping materials.

This choice should not be taken to indicate either superiority of inferiority of the thermoplastics, compared to traditional materials. The characteristics of any piping material could have been chosen for illustrative purposes.

(c) A total of 16 performance statements have been presented, as summarized in Table 4. Of these, nine (9) are recommended for use as general evaluation methods in considering the acceptance of thermoplastic piping in jurisdictions where the application is not already proven through satisfactory service history. Several statements are not sufficiently complete or proven to recommend for general use at this time, but may be useful as guides for establishing the format for information submitted by proponents of innovative piping materials, and for the review of such information. These latter statements await further work to develop suitable test methods before they can be considered complete. Discussion only is provided for two statements as an aid in defining the research required to develop the necessary quantification and reproducible test methods. The need for prescriptive product standards for quality control is not lessened by the development of performance criteria. Rather the performance criteria complement, or supplement, the prescriptive product standards, and may be useful in indicating areas in which the product standards might need further development, expansion or improvement.

(d) The work described in this report should aid the planning of systematic evaluations of future innovative piping materials proposed for use in plumbing systems. It should help to reduce the time required for evaluation and acceptance. For some materials, research and test development might be required for relevant criteria not investigated in this study.

Table 4. Status of Performance Evaluation Methodology for Thermoplastic Piping for Residential, Above-Ground Potable Water, Sanitary Drainage and Venting

No.	Attribute	Requirement	Measure/Criterion (and limiting value, if established)	Method of Evaluation/Test	Recommendations: Format and New, Existing or Modified Existing Test Recommended for General or Selective Use. Needed improvements indicated in commentary.	Recommendations: Utilize Format and Incomplete Test for Guidance in Submittal and Review of Proposals. Further Test Development Needed	Recommendations: Utilize Discussion to Define Need. Further Research and Test Development Needed
A.1.1	Functional Adequacy	Leak Resistance	Resistance to Sustained Pressure System shall withstand sustained miximum service pressures without rupture or leaking at 23°C (cold-water systems), 82°C (domestic hot-water systems, and 96°C (special high-temperature systems).	Long-term and short-time burst strength and hydrostatic design basis for systems may be tentatively evaluated by adaptation of the procedures of ASTM D1590, ASTM D1599 and ASTM D2837.	●		
A.1.2	Functional Adequacy	Leak Resistance	Resistance to Shock Pressure System shall withstand repetitive cyclic peak pressure (static plus shock of 1.03 MP_a for 350,000 cycles, at a temperature of 10°C for cold-water applications and at a temperature of 82° C for hot-water applications.	Long-term resistance to water hammer (shock pressure) for systems may be tentatively evaluated by use of a cyclic pressure test procedure similar to that described in NBSIR 77-1261.		●	
A.2.1	Functional Adequacy	Drainability and Hydraulic Capacity	Beam/Column Deflection and Ring Distortion Under normal service conditions: Angular deflection of pipe shall not exceed arctan 0.01. Out-of-roundness shall not exceed 10%.	Resistance to angular deflection and out-of-roundness may be tentatively evaluated by use of a cyclic hot water test procedure similar to that described in NBSIR 77-1261.		●	
A.2.2	Functional Adequacy	Drainability and Hydraulic Capacity	Continuity and Smoothness of Interior Surfaces Essential smoothness and continuity of internal surfaces shall be provided and maintained under normal service conditions. Surface relief inside new pipes and fittings shall not exceed ___mm, and the hydraulic resistance of any representative assemblage of pipes and fittings shall not be greater than that indicated by k/D = _____.	No definitive method has been developed for this purpose. See Commentary under A.2.2.		●	
A.3.1	Functional Adequacy	Acoustical Acceptability	Noise Reduction Between Living Units Through Interdwelling Walls Containing Piping NIC 40: living unit through interdwelling walls to spaces of avg. noise NIC 45: living unit through interdwelling walls to spaces of high noise.	Airborne sound insulation (NIC) measurements by App. A1 of ASTM E336. Airborne sound transmission loss (STC) for partitions by ASTM E90. Classification protocol (NIC and STC) by ASTM E413.	●		

Table 4. Status of Performance Evaluation Methodology for Thermoplastic Piping for Residential, Above-Ground Potable Water, Sanitary Drainage and Venting (Cont.)

No.	Attribute	Requirement	Measure/Criterion (and limiting value, if established)	Method of Evaluation/Test	Recommendations: Format and New, Existing or Modified Existing Test Recommended for General or Selective Use. Needed improvements indicated in commentary.	Recommendations: Utilize Format and Incomplete Test for Guidance in Submittal and Review of Proposals. Further Test Development Needed.	Recommendations: Utilize Discussion to Define Need. Further Research and Tast Development Needed.
A.3.2	Functional Adequacy	Acoustical Acceptability	Noise Reduction Between Living Units, Through Interdwelling Floor - Ceilings Containing Piping NIC and Field IIC 40: living unit through interdwelling floor-ceilings to spaces of avg. noise. NIC and Field IIC 45: living unit through interdwelling floor-ceilings to spaces of high noise. Ratings by documentation or laboratory measurement shall be at least 5 units greater than given above.	Same as for A.3.1, and in addition: laboratory measurement of impact sound transmission (using tapping machine) by ASTM E492.	●		
.3.3	Functional Adequacy	Acoustical Acceptability	Noise Reduction Between Spaces Within a Living Unit, Through Walls and Partitions Containing Piping NIC 28: within living unit through walls, chases or partitions where noise insulation is intended. STC rating by documentation or laboratory measurement shall be at least 7 units greater than given above.	Same as for A.3.1	●		
A.3.4	Functional Adequacy	Acoustical Acceptability	Noise Reduction Between Spaces Within a Living Unit Through Floor-Ceilings Containing Piping NIC and Field IIC 28: Within living unit through floor-ceilings where noise insulation is intended: STC and IIC ratings by documentation or laboratory measurement shall be at least 7 units greater than given above.	Same as for A.3.2	●		
A.3.5	Functional Adequacy	Acoustical Acceptability	Noise Level in Interior Spaces During Operation of Plumbing System A-weighted sound levels in living spaces shall not exceed 45 dB during imposition of representative hydraulic loads (drainage and water supply)	Sound level measurements by ANS S1.13 procedure, using type 1 meter specified in ANS S1.4. No definitive method has been developed for selection of representative hydraulic loads. See Commentary under A.3.5.	●		
B.1.1	Adequacy for Health / Safety	Toxicological Acceptability	Elution of Toxic Substances Inorganic chemical contaminents at points of use shall not exceed the levels set forth in the PHS Drinking Water Standards as amended by the National Interim Primary Drinking Water Regulations. Values provided in B.1.1.	Procedure shall be in accordance with NSF 14, BRAB/FCC TR No. 61 and "A Study of Plastic Pipe for Potable Water Supplies" by Tiedman and Milone.	●		
B.2.1	Adequacy for Health / Safety	Fire Safety	Fire Spread The fire endurance ratings of building elements as specified in the HUD MPS shall not be compromised by the installation of piping systems on, through or within such elements. Passage of flames and hot gases sufficient to ignite cotton padding, average temperature rise over unexposed surface exceeding 139°C or max rise exceeding 181°C at any point shall not occur within the required fire andurance rating period.	Tests shall be made of representative building elements with installed piping exposed to a standard increasing temperature by the procedure of ASTM E119.	●		

Table 4. Status of Performance Evaluation Methodology for Thermoplastic Piping for Residential, Above-Ground Potable Water, Sanitary Drainage and Venting (Cont.)

No.	Attribute	Requirement	Measure/Criterion (and limiting value, if established)	Method Evaluation/Test	Recommendations: Format and New, Existing or Modified Existing Test Recommended for General or Selective Use. Needed improvements indicated in commentary.	Recommendations: Utilize Format and Incomplete Test for Guidance in Submittal and Review of Proposals. Further Test Development Needed.	Recommendations: Utilize Discussion to Define Need. Further Research and Test Development Needed.
B.2.2	Adequacy for Health/Safety	Fire Safety	<u>Spread of Smoke and Toxic Gases</u> Excessive spread of smoke and toxic gases shall not occur from the exposed to the unexposed side of the building within the required fire endurance rating period. Generally accepted quantative limits have not been established for the purposes of this criterion.	No standard method has been established, see Commentary under B.2.2.			●
B.2.3	Adequacy for Health/Safety	Fire Safety	<u>Flame Spread</u> Surface flame spread ratings of exposed piping shall not exceed those for exposed building materials in the same locations as specified by the HUD MPS. Values provided in B.2.3.	Surface burning characteristics or surface flammability are determined in accordance with the procedures of ASTM E84 and ASTM E162.	●		
C.1.1	Adequacy for Durability/Maintainability	Retention of Properties for Essential Functional Capability	<u>Long-Term Stability of Dimensions and Strength</u> Following exposure to 100,000 cycles of a suitable hot-water exposure test: Angular deflection $\lessapprox$ 0.01 Permanent changes in length and mean diameter $\lessapprox$ 0.5% Reduction in impact resistance, ring-deflection strength and beam strength $\lessapprox$ 25% Burst strength and leak resistance shall not be less than required by A.1.1 and A.1.2	An adequate hot-water exposure test has not been developed for the purposes of this criterion, but tentative methods have been investigated. Standard and tentative methods exist for measuring some of the properties named at the left. See Commentary under C.1.1.		●	
C.1.2	Adequacy for Durability/Maintainability	Retention of Properties for Essential Functional Capability	<u>Resistance to Chemical Attack and Environmental Stress Cracking</u> Following exposure to a suitable chemical test(s), changes in dimensions and strength shall not exceed the limitations set forth in C.1.1.	A suitable chemical exposure test has not been developed. See Commentary under C.1.2.			●
C.1.3	Adequacy for Durability/Maintainability	Retention of Properties for Essential Functional Capability	<u>Resistance to Abrasion and Cutting</u> Abrasion and cutting under normal maintenance procedures shall not degrade performance potential in excess of the relevant limitations set forth in A.1.1, A.2.1, A.2.3 and C.1.1.	An abrasion and cutting test, suitable for simulating normal maintenance procedures, has not been developed. See Commentary under C.1.3.			●

(e) The approach used in this report should also be useful for:

(i) Facilitating acceptance decisions in jurisdictions which have not yet approved thermoplastics for above ground residential plumbing.

(ii) Facilitating better quality of design, installation and inspection through analysis of the important performance requirements and referencing of proper methods.

(iii) Providing general guidance in the approach to be taken in the review of suggestions and proposals for the use of new piping materials or for new applications of traditional materials not studied in the present investigation.

6.2 GENERAL ADEQUACY OF THERMOPLASTIC PIPING FOR RESIDENTIAL PLUMBING

Within the scope of this study, the findings indicate that ABS and PVC DWV piping, and CPVC water piping conforming to applicable ASTM and NSF standards should be adequate in a number of residential plumbing applications; provided that generally accepted good practice is employed in design and installation and that other applicable design and installation recommendations given herein are followed. Generally, the approving authority should find the applicable criteria presented herein useful in evaluating new piping materials or new applications for which service history is inadequate. The survey of current usage reported in Section 2 provides an up-to-date summary of allowable uses for thermoplastics for potable water supply and distribution, and for sanitary drainage and venting, as recommended by the model codes and a number of regulatory authorities.

The evaluation of toxicological factors relating to leachates from piping and of the structural criteria for underground piping were beyond the scope of this study; however, see sections 6.7 and 6.8 for considerations that might be involved in surveillance of these areas in the future.

6.3 FIRE SAFETY

(a) Plumbing walls and chases should be required to meet the applicable fire safety criteria for similar walls and chases not containing plumbing.

(b) One-hour fire rated walls containing ABS and PVC DWV piping may be expected to meet the one-hour fire endurance critiera when all the following conditions are satisfied.

1. The annular openings around the laterals penetrating the walls are sealed.
2. The wall cavity depth is 5 1/2 inches or more.
3. Soil and waste stacks are either 2 or 3 inches diameter.[6]

(c) Further studies may be needed for the development of adequate fire performance tests and data from such tests for plumbing assemblies in high rise buildings, for plumbing penetrating floor - ceilings, and for lateral configurations significantly unlike those used in this study. All the metallic systems evaluated in the test program met the fire spread criterion and the criterion for temperature rise on the unexposed wall surface for one hour. The tests did not address the fire performance of DWV systems in high rise construction, nor of DWV piping penetrating floor-ceiling assemblies.

(d) There is a need for developing a suitable, reproducible test procedure for quantitative measurements of smoke and gas accumulation in unexposed rooms adjacent to a fire and for establishing suitable performance levels.

6.4 THERMAL PERFORMANCE

Two tests are recommended for thermal properties that might affect long-term stability of dimensions and strength of PVC, ABS, CPVC, and PB. These are as follows:

(a) A "residual stress indicator", computed from glass transition temperature measurements.

(b) An oven test.

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[6] In the tests reported herein, a 4-inch PVC stack in a 9 1/2 inch cavity met the one-hour fire endurance criteria.

In general, hardness and its temperature coefficient may be useful in predicting relative resistance of piping materials to impact fracture at different temperatures. A test providing for intermittent exposure of a representative assembly to hot water should be utilized in conjunction with the tests recommended above. Hot water tests have been described, but these are not yet standardized.

It is believed that a realistic limitation of angular deflection between supports, either intermittent or permanent, would be arctan 0.01[7], and that permanent length change should not exceed 0.5% during and following exposure to 100,000 cycles of exposure to hot water (or a sufficient number of cycles to achieve dimensional stability, i.e. no further measurable change).

Additional work is needed to establish a suitable standard hot water exposure test. This test should be correlated with the oven test, with the test for hardness and its temperature coefficient, and with the test for residual stress indicator.

6.5 RESISTANCE TO SHOCK PRESSURE

A simulated "water hammer" test was developed for experimentation with CPVC that involves the application of 350,000 cycles of shock pressure produced by a closed loop electro-hydraulic machine programmed to generate a predetermined pressure "spike" with appropriate magnitude, duration and frequency. A frequency of application not greater than 2 Hz is recommended for test purposes with a spike duration of approximately 0.16s.

Results with this test on 1/2 in CPVC water tubing showed that a "fatigue life" curve of number of cycles to failure vs magnitude of shock pressure can be established for a given test temperature. The number of pulses to produce failure decreases as temperature is increased.

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[7] Equivalent to 1/8 in/ft, approximately.

At a temperature of 180°F (82°C), a temperature higher than the usual residential hot water service temperature, the 1/2 in CPVC tubing did not fail with the application of 350,000 pressure pulses to 150 psi/1.034 MPa (static pressure plus shock pressure). If 20 pulses occur during an average day in normal household service, 350,000 pulses would occur in approximately 50 years.

The results showed that the most critical parts of the piping assemblies tested were the fittings and the joints. It is important to follow industry recommendations carefully in the making of joints and to use NSF[8]-listed pipe, fittings and joint cements.

For the time being this tentative test method (which may also be appropriate for piping materials other than CPVC) should be considerd a leading candidate for standardization. Future work is recommended toward this end.

6.6 ACOUSTICAL PERFORMANCE

Five criteria for acoustical performance of piping assemblies are recommended. These provide measures for noise reduction through building elements containing plumbing and for noise level in interior spaces during operation of the plumbing system. Measurements are made in accordance with certain American National Standards (ANS) developed under ANSI procedures, and in accordance with certain ASTM standards. The principal areas of needed improvments are:

1. A detailed guide is needed for the hydraulic load to be imposed in evaluating the noise level generated by operation of the plumbing system.
2. For the evaluation of noise reduction through building elements, work is needed to reduce dependence on testing in the completed building. Component tests, or tests of small assemblies in the laboratory, should be considered

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[8] National Sanitation Foundation, Ann Arbor, Michigan.

and the results from such tests should be correlated with the present methods for completed buildings.

6.7 WATER QUALITY

This study did not include any investigation of water quality, per se, in thermoplastic piping systems. (See B.1.1). The NSF protocol (based on small specimens) was assumed adequate for the assurance of quality in potable water systems in relation to the impartation of bacteria, taste, odor, and toxic substances to the water by the piping materials. Further review and improvement of these methods may be needed if other studies should suggest that the NSF protocol is incomplete.

6.8 FUTURE NEEDS

In addition to the recommendations or considerations given in Sections 6.4, 6.5, 6.6 and 6.7, future work is recommended in the following areas:

(a) A review of existing criteria and evaluation techniques for underground applications of flexible piping.

(b) A review of existing criteria and evaluation techniques for the quality of water delivered to the potable water outlets in dwellings, as related to the piping materials.

(c) A review of the need for a manual or systematically organized index for designers/installers/inspectors that summarizes current generally accepted practice and indexes significant technical data and the requirements of codes and standards for piping. Such a manual should also include a concise descriptive tabulation of all significant standards and test methods for piping materials keyed to a realistic performance matrix.

(d) A continuing program to maintain a current interface with the industry, users, regulatory bodies and other government agencies (e.g., DOC, EPA, HEW, OSHA)[9] concerning water quality, fire safety, code and standards developments and other issues relating to piping systems, as appropriate. Organizations that have conducted or participated in surveys in these areas in recent years should be able to assist in this program.

6.9 ACKNOWLEDGMENT

Significant contributions to the value of this report have been made by a number of persons and organizations. Special appreciation is due to Mr. William J. Werner, General Engineer, Office of Policy Development and Research, Division of Energy, Building Technology and Standards, Department of Housing and Urban Development for valuable technical suggestions and policy guidance furnished during the course of the work; and to Dr. Frank W. Reinhart, until recently Technical Director, Plastics Pipe Institute, for up-to-date industry technical data on the properties of plastics piping and for current listings of applicable standards.

Thanks are also extended to several leading plumbing engineers and plumbing contractors for suggestions concerning scope and application of the work, and to the staff of the nationally recognized model code organizations for information on current code acceptance of thermoplastic piping for various applications.

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[9] Abbreviations of certain Federal Government Agencies, as follows:

DOC = Department of Commerce

EPA = Environmental Protection Agency

HEW = Health, Education and Welfare (Department of)

OSHA = Occupational Safety and Health Administration

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8. APPENDIX

8.1 Definitions and Nomenclature[10]

ABS: Acrylonitrile-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: Acrylonitrile, 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)

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

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[10] Definitions found in this section are intended to be identical, insofar as feasible, with those identified by the abbreviations (ASTM), (NSPC), and (PPI). For those definitions listed but not identified by one of the abreviations, either some modifications have been made to the definitions given by ASTM, NSPC or PPI, or the definitions may have been found elsewhere in the technical literature.

(ASTM) - American Society for Testing and Materials, ASTM D883

(NSPC) - National Standard Plumbing Code, 1975

(PPI) - Plastics Pipe Institute, PPI-TRI-November 1968.

Code: As related to plumbing work, usually an ordinance, with any subsequent amendment thereto, or any emergency rules or regulations which a city or 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 System: 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.

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" as defined in standard plumbing terminology.

Pipe: The term is applied generally to tubular products and materials commonly used to conduct or transport liquids 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 join individual lengths of pipe, 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/or 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 is 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 polyehtylene 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)

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.

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 relatively 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 sewer gases, without significantly retarding the flow of sewage or waste water through it.

Trap Arm: The horizontal drain extending from a trap to its vent or to the first connection to another drain, whichever comes first.

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 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 plumbing fixture or plumbing appliance, 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.

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)

8.2 MODEL CODES, SPECIFICATIONS AND STANDARDS

8.1.2 Model Plumbing Codes

Basic Plumbing Code (BPC)

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

National Standard Plumbing Code (NSPC)

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

Standard Plumbing Code (SPC)

Southern Building Code Congress International (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

8.2.2 Specifications and Standards

This section contains a partial list of widely-referenced thermoplastics piping standards including standards for raw materials; finished pipe and fittings; methods of test; and recommended practices for the design and installation of pipe and fittings, and of piping systems made of thermoplastics. Those standards marked with an asterisk (*) contain information on engineering design criteria and/or the closely related installation procedures. The years of issue are not generally given; however, in each instance the applicable date may be taken as the most recent issue date of the specification or standard prior to the publication date of this report.

The standards listed below are limited to those relating to ABS, CPVC, PB, PE, PP and PVC, in the context of the most likely plumbing applications in housing systems. Section 2 of this report provides general information on the status of approvals of several thermoplastic piping materials for various applications. Persons who may be considering the use of a thermoplastic piping material for a particular application in a particular community should consult the local approving authority for the current status of approvals in that community.

For a more comprehensive listing of Standards relating to plastics piping, the reader is referred to:

1. Chapter 14 of the Plastics Piping Manual, K. C. Ford and F. W. Reinhart, First Edition (1976). Obtainable from the Plastics Pipe Institute, 355 Lexington Avenue, New York, N.Y. 10017.

2. Annual Book of ASTM Standards, Part 34 - Plastic Pipe (current issue). Obtainable from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103.

Selected standards for the purpose of this report are listed below according to issuing organization (source).

ASTM STANDARD SPECIFICATIONS[11]

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:

1. Specifications for Plastics Pipe, Fittings, and Related Materials

A) Acrylonitrile-Butadiene-Styrene (ABS)

D1527 Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe, Schedules 40 and 80.

D1788 Acrylonitrile-Butadiene-Styrene (ABS) Plastics. (ANS K65.205)

D2282 Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe (SDR-PR). (ANS B72.3)

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

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

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[11] Standards having an "ANS" designation (shown here in parentheses) have been approved by the American National Standards Institute, 1430 Broadway, New York, N.Y. 10018

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

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

D2751 Acrylonitrile-Butadiene-Styrene (ABS) Sewer Pipe and Fittings. (ANS K65.59)

D3311 Drain, Waste and Vent (DWV) Plastic Fittings Patterns

F409 Acrylonitrile-Butadiene-Syrene (ABS) and Poly (vinyl chloride) (PVC) Accessible and Replaceable Plastic Tube and Tubular Fittings

B) Poly(vinyl chloride) (PVC)

D1784 Rigid Poly(vinyl chloride) (PVC) Compounds and Chlorinated Poly(vinyl chloride) (CPVC) Compounds

D1785 Poly(vinyl chloride) (PVC) Plastic Pipe, Schedules 40, 80, and 120. (ANS B72.7) (includes CPVC 4116)

D2241 Poly(vinyl chloride) (PVC) Plastic Pipe. (SDR-PR) (ANS B72.2)

D2464 Threaded Poly(vinyl chloride) (PVC) Plastic Pipe Fittings, Schedule 40. (ANS K65.166)

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

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

D2665 *Poly(vinyl chloride) (PVC) Plastic Drain, Waste, and Vent Pipe and Fittings. (ANS K65.56)

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

D2740 Poly(vinyl chloride) (PVC) Plastic Tubing (ANS B72.22)

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

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

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

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

C) Chlorinated Poly(vinyl chloride) (CPVC)

D1784 Rigid Poly(vinyl chloride) (PVC) Compounds and Chlorinated Poly(vinyl chloride) (CPVC) Compounds

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

D) Polyethylene (PE)

D1248 Polyethylene Plastics Molding and Extrusion Materials.

D2104 Polyethylene (PE) Plastic Pipe, Schedule 40. (ANS B72.8)

D2239 Polyethylene (PE) Plastic Pipe. (SDR-PR) (ANS B72.1)

D2447 Polyethylene (PE) Plastic Pipe, Schedules 40 and 80 Based on Outisde Diameter. (ANS B72.13)

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

D2610 Butt Fusion Polyethylene (PE) Plastic Pipe Fittings, Schedule 40. (ANS K65.160)

D2611 Butt Fusion Polyethylene (PE) Plastic Pipe Fittings, Schedule 80. (ANS K65.159)

D2683 Socket-Type Polyethylene (PE) Fittings for SDR 11.0 Polyethylene Pipe.

D2737 Polyethylene (PE) Plastic Tubing.

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

D3197 Insert-type Polyethylene Fusion Fittings for SDR 11.0 Polyethylene Pipe.

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

D3350 Polyethylene Plastics (PE) Pipe and Fittings Materials.

E) Polybutylene (PB)

D2581 Polybutylene (PB) Plastics

D3309 Polybutylene (PB) Plastic Hot Water Distribution Systems

2. Specifications for Plastic Piping Solvent Cements and Joints

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

D2564 * Solvent Cements for Poly(vinyl chloride) (PVC Plastic Pipe and Fittings. (ANS B72.16)

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

D3139 Joints for Plastic Pressure Pipes Using Flexible Elastomeric Seals

D3212 Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals

3. Methods of Test of Thermoplastic Pipe and Tubing

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

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

D2122 Determining Dimensions of Thermoplastic Pipe and Fittings.

D2152 Quality of Extruded Poly(vinyl chloride) Pipe by Acetone Immersion. (ANS B72.9)

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

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

D2444 Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight) (ANSI SK65.169)

D2837 *Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials. (ANS K65.153)

D2924 External Pressure Resistance of Plastic Pipe.

4. Recommended Practices

D2153 *Calculating Stress in Plastic Pipe Under Internal Pressure. (ANS B72.10)

D2321 *Underground Installation of Flexible Thermoplastic Sewer Pipe. (ANS K65.171)

D2657 *Heat Joining of Thermoplastic Pipe and Fittings. (ANS B72.17)

D2774 *Underground Installation of Thermoplastic Pressure Piping.

D2855 *Making Solvent Cemented Joints with Poly(vinyl chloride) (PVC) Pipe and Fittings. (ANS K65.55)

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

5. Definitions and Terminology

D833 Standard Definitions of Terms Relating to Plastics.

D2749 Standard Symbols for Dimensions of Plastic Pipe Fittings. (ANS K65.58)

F412 Standard Definitions of Terms Relating to Plastic Piping Systems.

6. Summary of Selected ASTM Tests

Table 5 gives a brief description of selected ASTM tests on properties of plastics and plastics pipe and fittings. Some of these properties may be of interest in the correlation of service performance and laboratory tests as required in the development of viable, material-dependent, performance tests for piping systems.

Table 5. Brief Description of Selected ASTM Tests on Properties of Plastics, and of Plastics Pipe, Tube and Fittings

Designation	Property Measured	Nature of Test
D 256	Impact resistance (Izod)	Energy required to break notched specimen is determined.
D543	Resistance to chemical reagents	Changes in weight, dimensions, appearance and selected strength properties of prepared specimens are determined after immersion for 7 days in specified standard reagents at a temperature of 23 ^{o}C.
D 621	Deformation under load	Deformation in compression after 24 hours is determined.
D 638	Tensile properties	Tensile stress is determined as a function of strain, at one or more rates of strain.
D 648	Deflection temperature under load	The temperature at which a beam specimen deflects a specified amount under a given load with gradually increasing temperature is determined.
D 671	Flexural fatigue	Resistance to deterioration from cyclic stress is determined from machines flat specimens. Cycles-to-failure are determined at several different stress amplitudes at a frequency of 30 Hz.
D 695	Compressive properties	Compressive strength is calculated as the stress required to cause rupture or to deform specimen a given percentage of its thickness.
D 696	Coefficient of linear thermal expansion	The change in length of a cylindrical specimen is measured while heating and while cooling, using a specified apparatus. The coefficient of linear expansion is calculated as the average of the values obtained for heating and cooling.
D 732	Shear strength	Shear strength is calculated from the load required to punch a hole in the specimen.

Table 5. Brief Description of Selected ASTM Tests on Properties of Plastics, and of Plastics Pipe, Tube and Fittings--Continued

Designation	Property Measured	Nature of Test
D 746	Brittleness temperature by impact	A specified impact is applied to cantilevered specimens at various temperatures. The brittleness temperature is that temperature at which 50% of the specimens fail.
D 747	Stiffness	Angular deflection is determined as a function of load, and stiffness in flexure is calculated.
D 756	Resistance to accelerated service conditions	Weight change of samples of interest is determined after oven heating in accordance with specified temperatures and cyclic exposure. Physical properties of interest may be determined before, during and/or after exposure.
D 785	Rockwell hardness	Indentation by a spherical impressor under load is determined.
D 790	Flexural properties	Flexural strength is determined as the load at failure, or as flexural stress at 5% strain.
D 793	Short-time stability at elevated temperatures	The quantity of hydrogen chloride evolved from a 10 g cut or shredded specimens of plastic containing chlorine during heating for 30 minutes at a temperature of 180°C is determined by specified chemical means.
D 794	Permanent effect of heat	Effect of oven heating on properties of interest is observed. Applicable to cut specimens as well as molded parts in finished form.
D 864	Coefficient of cubical thermal expansion	The volume change of a cylindrical specimen immersed in mercury is determined on heating and on cooling. The coefficient of cubical expansion is calculated as the average of the values for heating and cooling.
D 953	Bearing strength	Bearing strength of sheet specimens in compression or tension is determined at 4% deformation. The relationship between bearing stress and deformation, as measured by a specified procedure, is obtained.

Table 5. Brief Description of Selected ASTM Tests on Properties of Plastics, and of Plastics Pipe, Tube and Fittings--Continued

Designation	Property Measured	Nature of Test
D 1043	Stiffness properties in torsion	Angular rotation of a rectangular specimen is determined within the range 5-100 deg of arc for rigid materials and 10-100 deg for rigid materials. Determinations are made at different temperatures. Modulus of rigidity is calculated for each temperature, and the relationship of modulus of rigidity and temperature is determined.
D 1180	Bursting strength of tubing	The internal pressure resulting in rupture of prescribed lengths of plastic tubing subjected to pressure increasing at a specified rate at a a temperature of 23 °C is determined.
D 1299	Shrinkage at elevated temperature	Thickness change in disk specimens of molded and laminated thermosetting plastics is determined after heating for a specified period of time at a specified temperature between 70 °C and 230 °C. The minimum period of heating shall be that for which shrinkage equals or exceeds 0.25 mm, as measured with a specified apparatus. The method provides a means of classifying plastics with respect to shirnkage on a relative basis.
D 1435	Outdoor weathering	Cut or molded specimens are exposed outdoors, facing south and tilted 45°. Changes in properties of interest are determined.
D 1525	Softening temperature (Vicat)	Penetration of a flat-ended penetrator under gradually increasing temperature is measured. Softening point is the temperature at which 1 mm penetration occurs.
D 1598	Long-term strength of pipe under internal hydrostatic pressure	Time-to-failure of pipe specimens at constant pressure is measured. The relationship between pressure and time-to-failure is established. Hoop stress at failure is calculated.

Table 5. Brief Description of Selected ASTM Tests on Properties of Plastics, and of Plastics Pipe, Tube and Fittings--Continued

Designation	Property Measured	Nature of Test
D 1599	Short-time strength of pipe under internal hydrostatic pressure	The pressure at which pipe specimens are ruptured is determined by continuously increasing the internal pressure over a time interval not greater than 70 seconds. Hoop stress at failure is calculated.
D 1693	Environmental stress cracking	Annealed and conditioned specimens are nicked and then placed in a reagent and held at 50° C. Time to first crack and percentage of failures (cracks) are reported.
D 1708	Tensile properties	Yield strength, tensile strength, tensile strength at break, percentage elongation at break and percentage elongation at yield point are determined for small cut or machined specimens. The speed of testing is chosen such that the rate of straining is approximately the same as that obtained where the material is tested according to ASTM D 638 for larger specimens.
D 1822	Tensile impact strength	Energy required to break specimen in tension by impact is determined.
D 1939	Residual stress	Excess residual stress in extruded or molded Acrylonitrile-Butadiene-Styrene (ABS) parts is indicated by the presence of cracking of the specimen after 30 and 120 seconds immersion in glacial acetic acid at a temperature of 23 °C. Specifications are given for preparation of specimens for the aparatus and for the procedure.
D 2105	Longitudinal tensile properties	Tensile load and elapsed time for a strain of 0.02 is measured in an apparatus that subjects pipe specimens to continuously increasing longitudinal tension at a specified grip separation velocity. Calculations are made of tensile strength, elongation, rates of stressing and straining, and elastic modulus.
D 2115	Oven heat stability	Relative thermal stability of sheet or molded poly (vinyl chloride) (PVC) compounds is determined by discoloration due to exposure at an elevated temperature in a controlled oven. Sheet specimens of specified dimensions are exposed to an oven temperature of 177 °C (351 °F) unless another temperature is specified. Observation of discoloration and other visible changes are made at selected periodic intervals.

Table 5. Brief Description of Selected ASTM Tests on Properties of Plastics, and of Plastics Pipe, Tube and Fittings--Continued

Designation	Property Measured	Nature of Test
D 2143	Cyclic internal pressure Strength	The number of pressure cycles to failure, hoop stress at failure and statistical correlation coefficient are determined for a sample of thermosetting plastic pipe comprising at least twelve specimens. A prescribed apparatus is utilized, designed to produce 25 pressure cycles per minute. The peak test pressures shall be adjusted to different levels so that three specimens fail at a cycle count in excess of 10^3 cycles; three in excess of 10^4 cycles; three in excess of 10^5; and three in excess of 10^6. The test is suitable for application at any realistic temperature.
D 2152	Resistance to acetone	Swelling, flaking or disintegration is observed for PVC specimens immersed in anhydrous acetone solution for 20 minutes.
D 2236	Dynamic mechanical properties	The elastic and nonelastic components of the complex modulus of plastics of logarithmic mean equal to or less than 1 are determined by means of a torsional pendulum technique utilizing rectangular or cylindrical specimens of specified dimensions.
D 2240	Durometer hardness	Indentation by a pointed indentor is measured.
D 2290	Tensile Strength	Apparent tensile strength of tublar plastic products is determined for ring-shape specimens subjected to circumferential stress by a machine having a constant rate of crosshead movement and a load indicator. Tests are made at a machine speed of 2.5 mm/minute for fiber-reinforced thermoset specimens and 12.7 mm/minute for extruded of molded specimens. Yield and ultimate loads are measured and corresponding stresses calculated.
D 2412	External loading properties of pipe	The load and deflection of a plastic pipe specimen at cracking during the application of a compressive load by means of parallel flat steel plates with an approach speed of 1/2 inch per minute at a temperature of 23° C are determined by the use of a specified testing machine. Pipe deflection, in percent, and "stiffness" factor are calculated from formulae provided.

Table 5. Brief Description of Selected ASTM Tests on Properties of Plastics, and of Plastics Pipe, Tube and Fittings--Continued

Designation	Property Measured	Nature of Test
D 2444	Impact resistance of pipe and fittings	The energy required to produce failure in thermoplastic pipe or fittings is determined under specified conditions of impact by means of a tup (falling weight). Median impact resistance is determined with 20 test specimens of each sample. The apparatus, procedure and method of calculation are specified.
D 2445	Thermal oxidative stability	Resistance of propylene plastics to oxidation is measured when exposed to oxygen at 150 °C. Additional evaluations may be made at other temperatures between 100 and 150 °C. Total exposure time for pellet specimens to become embrittled is determined. The results provide an indication of relative degree of stabilization. The method is considered an accelerated test. The apparatus and procedure are prescribed.
D 2552	Environmental stress rupture	Susceptibility of type III polyethylene to mechanical failure under certain conditions of load and environment is determined. Specimens of prescribed dimensions are cut from molded sheet, and exposed to a constant load in tension in the presence of a surface-active agent. The elapsed time to failure is observed. The test is considered applicable to other types of plastics. The specified surface-active reagent, Igepal CO-630, is considered to yield results indicative of what may be expected from a wide variety of other substances which are not absorbed appreciably by the polymer. The apparatus and procedure are specified.
D 2583	Indentation hardness by barcol impressor	Indentation hardness of both reinforced and nonreinforced rigid plastics is determined by the use of a specified impressor apparatus according to a particular procedure The apparatus is calibrated for hardness values ranging up to 100 for the hardest materials (eg. glass).
D 2586	Hydrostatic compressive strength of cylinders	Compressive strenth properties of filament-wound glass reinforced plastic cylinders of specified dimensions are determined. Compressive strength is calculated from the value of external hydrostatic pressure at collapse. The method is considered useful in manufacturing quality control programs. The apparatus and procedure are specified.

Table 5. Brief Description of Selected ASTM Tests on Properties of Plastics, and of Plastics Pipe, Tube and Fittings--Continued

Designation	Property Measured	Nature of Test
D 2837	Hydrostatic design basis	A method is described for obtaining hydrostatic design basis for thermoplastic pipe, utilizing long-term internal hydrostatic strength data obtained by ASTM method D 1598. The extrapolated stress at 100,000 hours is categorized to give the hydrostatic design basis for the pipe material.
D 2924	External pressure resistance of pipe	The resistance of reinforced thermosetting plastic pipe to external pressure is determined. A specimen is loaded to failure in a short time interval by means of continuously increasing external fluid pressure. Fluid is maintained inside the pipe specimen, and change in inside volume is monitored. Failure pressure, type of failure and time to failure are determined. Buckling and compressive scaling constants are calculated for specimens that fail by buckling and collapse, respectively. The apparatus and procedure are specified.
D 2925	Beam deflection of pipe	The deflection as a function of time of a specimen of reinforced plastic pipe supported as a simple beam while carrying full bore flow of water at an elevated temperature is determined. The procedure is considered applicable to other test media as well. The EI values are calculated from the deflection data and the pipe dimensions. The test is continued for 1000 hours or until the deflection exceeds 12.7 mm (1/2 in.) or does not increase by more than 0.025 mm (0.001 in.) in two consecutive 24-hour periods. The apparatus and procedure are specified.
D 2990	Creep	Methods are given for measuring the extension or compression of plastics as a function of time-to-rupture or failure of a specimen subject to constant tensile or compressive load under specified environmental conditions. The apparatus and procedures are specified.
D 2991	Stress relaxation	A method is given for determining determining the time dependence of stress (stress relaxation) of plastics resisting long-duration constant strains at conditions of constant temperature and relative humidity and negligible vibration. Stress and strain as a function of time are determined at intervals for 1000 hours following the application of a pre-selected load or strain. Apparatus,test specimens and procedure are specified.

Table 5. Brief Description of Selected ASTM Tests on Properties of Plastics, and of Plastics Pipe, Tube and Fittings--Continued

Designation	Property Measured	Nature of Test
D 2992	Hydrostatic design basis for pipe and fittings	Two alternative procedures are given for obtaining a hydrostatic design basis for reinforced thermosetting resin pipe, fittings, and piping systems. The experimental basis for Procedure A is ASTM D 2143 (cyclic pressure strength). The experimental basis for Procedure B is ASTM D 1598 (long-term hydrostatic strength). Methods are given for extrapolation to 150 x 10^6 cycles (11.4 years) of a log-log plot of the linear regression line for hoop stress versus cycles to failure (Procedure A), and to 100,000 hours of a log-log linear regression line for hoop stress versus time-to-failure (Procuedure B). The hydrostatic design stress is obtained by multiplying the hydrostatic design basis (as determined from Procedure A or B) by a service (design) factor. The pressure rating is calculated from the hydrostatic design stress value by means of the ISO hoop stress formula, taking into account the pipe diameter and wall thickness.

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)

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

L-P-320b Pipe and Fittings, Plastic (PVC, Drain, Waste and Vent)

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

Department of Defense Military Standards

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

MIL-A-22010A(1) Adhesive, Solvent-Type, Polyvinyl Chloride

MIL-P-14529B Pipe, Extruded, Thermoplastic

MIL-P-22011A Pipe Fittings, Plastic, Rigid, High Impact, Polyvinyl Chloride, (PVC) and Poly 1, 2, - Dichloroethylene

MIL-P-22634A Pipe and Pipe Fittings, Polyethylene, for Low-Pressure Waste and Drainage Systems

MIL-P-82056(1) Pipe and Pipe Fittings, Plastic, for Drain, Waste and Vent Service

NBS Product Standards

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

NBS Product Standard PS10-69 Polyethylene (PE) Plastic Pipe (Schedule 40-Inside Diameter Dimensions). (ASTM D 2104; ANS B 72.8)

NBS Product Standard PS11-69 Polyethylene (PE) Plastic Pipe (SDR). (ASTM D 2239; ANS B 72.1)

NBS Product Standard PS12-69 Polyethylene (PE) Plastic Pipe (Schedules 40 and 80 - Outside Diameter Dimensions). (ASTM D 2447; ANS B 72.13)

NBS Product Standard PS 18-69 Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe (Schedules 40 and 80). (ASTM D 1527; ANS B 72.5)

NBS Product Standard PS 19-69 Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe (Standard Dimension Ratio). (ASTM D 2282; ANS B72.3)

NBS Product Standard PS 21-70 Poly(vinyl chloride) (PVC) Plastic Pipe (Schedules 40, 80 and 120). (ASTM D 1785; ANS B72.7)

NBS Product Standard PS 22-70 Poly(vinyl chloride) (PVC) Plastic Pipe (Standard Dimension Ratio) (ASTM D2241; ANS B72.72)

FHA/HUD

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

1. Use-of Materials Bulletins

FHA UM-26c	*Styrene-Rubber Plastic Drain and Sewer Pipe and Fittings
FHA UM-31e	*Polyethylene Plastic Pipe and Fittings for Domestic Water Service
FHA UM-41a	PVC Plastic Pipe and Fittings for Domestic Water Service
FHA UM-43	Acrylonitrile-Butadiene-Styrene Plastic Pipe and Fittings for Domestic Water Service
FHA UM-53a	*Polyvinyl Chloride Plastic Drainage, Waste, and Vent Pipe and Fittings
FHA UM-54	ABS (Acrylonitrile-Butadiene-Styrene) Plastic Drainage, Waste, and Vent Pipe and Fittings
FHA UM-61a	(CPVC) Hot and Cold Water Distribution Systems - Chlorinated Polyvinyl Chloride
FHA UM-68	(PB) Hot and Cold Water Distribution system - Polybutylene

2. Minimum Property Standards

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

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

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

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

American National Standards

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

In the ANS 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 similar and more recently updated. To conserve space, the standards have been listed under the ASTM grouping with a cross reference to the ANS designation.

NSF Standards

National Sanitation Foundation
NSF Building
Ann Arbor, Michigan 48105

NSF Standard No. 14 Thermoplastic Materials, Pipe, Fittings, Valves, Traps and Joining Materials

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).

IAPMO Standards

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

Installation Standards (IS)

IS-5 ABS Building Drain, Waste and Vent Pipe and Fittings

IS-7 Polyethylene Building Supply for Water Service and Yard Piping

IS-8 Solvent Cemented PVC Pipe for Water Service and Yard Piping

IS-9 PVC Building Drain, Waste and Vent Pipe and Fittings

IS-14 PVC Pipe and Fittings with Rubber Gasketed Joints for Cold Water Service and Yard Piping

Product Standards (PS)

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

PS-24 Polyethylene Pipe (Building Supply)

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

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

8.3 SOURCES OF INDUSTRY TECHNICAL INFORMATION RELATING TO THE SELECTION OF MATERIALS AND TO THE DESIGN AND INSTALLATION OF THERMOPLASTIC PIPING SYSTEMS

8.3.1 Publications of the Plastics Pipe Institute

Plastics Pipe Institute
355 Lexington Avenue
New York, New York 10017

1. PPI Technical Reports (TR)

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)

TR3-JUN 1975 Policies and Procedures on Developing Recommended Hydrostatic Design Stresses for Thermoplastic Pipe

TR4-JUN 1975 Recommended Hydrostatic Strength and Design Stresses for Thermoplastic Compounds

TR5-OCT 1975 List of Standards for Plastic Piping

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

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 (Replaced by ASTM D2855)

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

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

TR21-SEPT 1973 Thermal Expansion and Contraction of Plastic Pipe

TR24-MAR 1975 Deflection of Thermoplastic Pipe Resulting from Thermal Cycling

TR25-JUN 1975 Polyvinyl Chloride (PVC) Gravity Sewer Piping Systems

TR26-APR 1975 Recommendations for Storage and Handling of Polyvinyl Chloride Plastic (PVC) Pipe

TR27-APR 1975 Thermoplastic Drainage Systems for Residential Applications

2. PPI Technical Notes (TN)

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

TN5-JAN 1972 Testing Equipment

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 Thermoplastics Pipe and Fittings

TN9-AUG 1973 Coiling PVC Pipe and Tubing

TN10-MAR 1975 Descriptions of Plastic Piping Joints

3. PPI Recommendations and Statements (RS)

RS A Limiting Water Velocities in Thermoplastic Piping Systems, January 5, 1971. Now in PPI-TR16-JUNE 1972 as Section 3.9

RS C Pressure Rating of PVC Plastic Piping for Water at Elevated Temperatures, August 1, 1973.

RS E Criteria for Joing Various Polythylene Materials to one another by Heat Fusion Techniques, April 3, 1974.

RS F Crush Strength and Flexibility of Thermoplastic Piping, August 5, 1974.

RS H Noise in Piping, April 15, 1975

8.3.2 Company Publications

Individual manufacturers of raw materials and finished products have published many documents that provide valuable technical data useful in the selection of materials, the design and installation of thermoplastic piping systems, the analysis or classification of test methods, the comparison of chemical and physical properties of thermoplastics, inspection techniques etc. These publications sometimes provide more detailed and specialized information than the documentation issued by the Plastics Pipe Institute. In many instances this could be useful to the design/specifying engineer, the plumbing contractor, the plumber, and the plumbing inspector.

A comprehensive listing of these documents would be voluminous, and is outside the scope of this report. For the benefit of those who may wish to obtain these kinds of technical data from individual manufacturers, a partial listing of company names and addresses is provided:

Borg-Warner Corporation
Marbond Dividion
P. O. Box 68
Washington, W. Va 26181

Celanese Piping Systems
Celanese Plastics Compnay
4550 Cemetery Road
Hilliard, Ohio 43026

Charlotte Pipe and Foundry Company
Plastics Division
P. O. Box 991
Monroe, North Carolina 28110

Eastman Chemical Products, Inc.
P. O. Box 431
Kingsport, Tennessee 37662

Genova Corporation
300 Rising Street
Davison, Michigan 48423

R.&.G. Sloane Mfg. Co., Inc.
7606 North Clybourn Avenue
Sun Valley, California 91352

Uniroyal, Inc.
Uniroyal Chemical Division
Naugatuck, Conn. 06770

For a more comprehensive listing of manufacturers, the reader is referred to the current issue of the NSF Seal of Approval Listing of Plastic Materials, Pipe, Fittings, and Appurtenances for Potable Water and Waste Water, obtainable from:

National Sanitation Foundation
NSF Building
Ann Arbor, Michigan 48105

Alternatively, a list of member companies may be obtained from:

Plastics Pipe Institute
355 Lexington Avenue
New York, N.Y. 10017

8.3.3 Supplemental Bibliography of Individual Technical Papers by Industry Experts

Nielsen, L. S.: Recommendations for use of Plastic Piping for Drainage and Vent Systems in Buildings, New York State Building Code Technical Report No. 3, August 1966.

Reinhart, F. W.: Engineering properties of plastics applicable to water piping. Journal of the Missouri Water and Sewerage Conference. Annual proceedings, V. 37, No. 1-4, Jan.-Oct. 1966. pp. 19-29.

Reinhart, F. W.: Hydrostatic strength and design stresses for thermoplastic pipe with wter. ASTM Special Technical Publication No. 375: Similuated Service Testing in the Plastics Industry. 1965. pp. 30-48.

Reinhart, F. W.: Long-term hydrostatic strength characteristics of thermoplastics pipe. Polymer Engineering & Science, V. 6, No. 4, Oct. 1966, pp. 285-295.

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Richard, K. And Ewald, R.: Extrapolationsverfahren, Sicherheitsbeiwerte und zulaessige Rohrwandbeanspruchung von Polyaethylene und PVC-Rohren. Kunststoffe, V. 49, No. 3, March 1959. pp. 116-120. Extrapolation, safety factors and maximum working pressures relating to polyethylene and PVC pipes, German Plastics, March 1959. pp. 7-9. German & English.

Richard, K. and Ewald, R.: Extrapolation methods -- P.V.C. and polythene tubes. Plastics (London), V. 24, No. 259, April 1959. pp. 153-156.

Richard, K., Gaube, E. and Diedrich, G.: Die Pruefung der Schlagzaehigkeit von PVC Rohren. (Determination of impact strength of PVC pipe). Kunststoffe, V. 51, No. 8, Aug. 1961. pp. 431-438. German.

Richard, K. And Diedrich, G.: Standfestigkeitseigenschaften von einigen Hochpolymeren. (Creep rupture strength of some high polymers). Kunststoffe, V. 45, No. 10, Oct. 1955. pp. 429-443. German

Richard, K., Diedrich, G. and Gaube, E.: Zeitstandfestigkeit von Kunststoffrohren; PVC und Ziegler-polyaethylen als Rohrwerkstoffe. (Creep rupture strength of plastic pipes; PVC and polyehtylene as pipe materials). Kunststoffe, V.49, No. 11, Nov. 1959. pp. 616-621. German.

Sansone, L. F., Jr.: A comparison of short-time versus long-time properties of plastic pipe under hydrostatic pressure. SPE Journal, V. 15, No. 5, May 1959. pp. 418-426.

Tiedeman, W. D.: Plastic service pipe -- testing program. American Water Works Assoc. Journal, V. 45, No. 7, 1953. pp. 752-763.

Tiedeman, W. D.: Studies on plastic pipe for potable water supplies. American Water Works Assoc. Journal, V. 46, No.8, 1954. pp. 775-787.

Van der Voort, H. F.: Characteristics of polyvinyl chloride conduit, insulated wire and piping in fire situations. Fire Journal, v. 66, no. 6, 1972. pp. 91-94.

Vancrombrugge, R.: Kruip- en vermoeiingsterke van gelaste pe buizen. (Creep and fatigue resistance of welded polyethylene pipes). Plastica, V. 26, No. 5, May 1973. pp. 199-207. Dutch.

Vetter, H.: Zur Preufung von Kunststoffrohren. (Notes on the testing of plastic pipe). Kunststoffe, V. 56, No. 4, April 1966. pp. 250-253. German.

Voight, J.: Kunststoffrohre unter statischer und pulsierender Innendruck beanspruchung. (Plastic pipe under static and intermittent internal pressure stress). Kunststoffe, V. 55, No. 6, June 1965. pp. 460-464. German.

Wal, A. A. van der and Heyer, S.: Allowable stresses and quality control of rigid PVC pipes. Rubber and Plastics Age, V. 41, Feb. 1960. pp. 169-171, 173, 175, 177.

Wal, A. A. van der: Allowable working stress in rigid PVC pipes. Rubber and Plastics Age, V. 40, No. 2, Feb. 1959. pp. 156-158.

Watkins, R. K., Szpak, E. and Allman, W. B.: Structural design of polyethylene pipes subjected to external soil loads. Paper presented at the ASTM D-20 meeting, Boston, Mass. Oct. 15, 1973.

Wilging, R. C.: Stress rupture testing of PVC pipe. Modern Plastics, V. 51, No. 10, Oct. 1974. pp. 90-92.

8.4 UNITS OF MEASURE AND S.I. CONVERSION FACTORS

An NBS document, NBS Guidelines for The Use of Metric System, LC 1056, originally issued November 1974 and most recently revised August 1977, reaffirms, clarifies and strengthens the policy of NBS to lead in the use of the metric system. In keeping with the intent of LC 1056, the the following guidelines have been adopted for this report:

1. Equations or formulas for which metric equivalents do not yet appear in the engineering literature 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 for descriptive data not affecting calculations or results is required. For example when nominal values of units appear as adjectives such as 3-inch pipe, 2 x 6-inch stud, 2-oz. bottle, etc., designations expressed in customary units are acceptable.

4. Exceptions to the exclusive use of S.I. units are allowed when communication or readership would be limited by the exclusive use of S.I. units.

5. The following conversion factors, adapted from ASTM E380-74, Metric Practice Guide, are appropriate for units of measure that appear in this report:

Length

1 inch (in.) = 0.0254 meter (m)

1 foot (ft.) = 0.3048 meter (m)

Mass

1 pound-mass (lbm) = 0.4535924 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 meter 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 meter^3 (m^3)
= 3.785412 leters (1)

Flow Rate

1 U.S. gallon per minute (gpm) = 0.0000630902 meter^3/second (m^3/s)
= 63.0902 centimeters^3/second (cm^3/s)
= 0.0630902 liter/second (1/s)

1 cubic foot per second (cfs) = 0.02831684 meter^3/second (m^3/s)
= 28.31685 leters/second (1/s)

6. S.I. prefixes are used as defined by the following tabulation:

Factor	Prefix	Symbol
10^6	mega	M
10^3	kilo	k
10^2	hecto	h
10^1	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM.
BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION OR REPORT NO. BSS 111

2. Gov't Accession No.

3. Recipient's Accession No.

4. TITLE AND SUBTITLE
Investigation of Standards, Performance Characteristics and Evaluation Criteria for Thermoplastic Piping in Residential Plumbing Systems

5. Publication Date
May 1978

6. Performing Organization Code

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

8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

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

10. Project/Task/Work Unit No.
462 4190

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
Division of Energy, Building Technology and Standards
Department of Housing and Urban Development
Washington, D.C. 20410

13. Type of Report & Period Covered
Final

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES
Library of Congress Catalog Card Number: 78-600037

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 application of the performance concept to the evaluation of piping systems of innovative materials is explored. User needs are considered and several material-related physical parameters are studied that might be used as measures of satisfaction of the user needs.

Information was reviewed on usage, performance characteristics and standards for thermoplastic pipe and fittings, and special laboratory tests were made to study selected characteristics and test methods. A number of performance statements and evaluation methods are recommended or discussed that relate to characteristics associated with polyvinyl chloride (PVC), acrylonitrile-butadiene-styrene (ABS) and chlorinated polyvinyl chloride (CPVC). This approach was taken to illustrate the application of performance evaluation methodology to plumbing materials.

The results indicate that PVC,ABS,and CPVC can be used satisfactorily in a number of residential plumbing applications if appropriate attention is given to the selection of the materials, to the design of the piping system and to important installation details. Further research and education are needed for the general application of performance evaluation methodology as a basis for wider and more uniform acceptance of the above-mentioned thermoplastics as well as other materials for plumbing piping. However, the results of this study can be useful in expediting the systematic performance evaluation of future innovative piping materials.

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)* Acoustical performance (plumbing piping); fire performance (plumbing piping); plumbing performance evaluation (piping); structural performance (thermoplastic plumbing piping); thermoplastic pipe usage (residential plumbing).

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