Designation: D 2513 – 03~~b~~4

An American National Standard

Standard Specification for Thermoplastic Gas Pressure Pipe, Tubing, and Fittings[1]

This standard is issued under the fixed designation D 2513; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers requirements and test methods for material (see Appendix X1) dimensions and tolerances, hydrostatic burst strength, chemical resistance, and impact resistance of plastic pipe, tubing, and fittings for use in fuel gas mains and services for direct burial and reliner applications. The annexes provide specific requirements and test methods for each of the materials currently approved. If and when additional materials are available, specific annex requirements will be added. The pipe and fittings covered by this specification are intended for use in the distribution of natural gas. Requirements for the qualifying of polyethylene systems for use with liquefied petroleum gas are covered in Annex A1.

1.1.1 This specification does not cover threaded pipe. Design considerations are discussed in Appendix X2. In-plant quality control programs are specified in Annex A3 and Annex A4.

1.2 The text of this specification references notes, footnotes, and appendixes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the specification.

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are provided for information purposes only.

1.4 The following is an index of the annexes and appendixes in this specification:

~~Annex~~	~~Subject~~
Annex	Subject
A1	Polyethylene (PE) Pipe and Fittings
A2	Poly (Vinyl Chloride) (PVC) Pipe and Fittings for Maintenance or Repair
A3	In-Plant Quality Control for all materials up to 12 in.
A4	In-Plant Quality Control for PE materials between 14 and 24 in.
A5	Polyamide (PA) Pipe and Fittings
A6	Magnetic-detectable Polyethylene Pipe
~~Appendixes~~	~~Subject~~
A7	Crosslinked Polyethylene (PEX) Pipe
Appendixes	Subject
X1	New Materials
X2	Design Consideration
X3	Gas Pressure Pipe and Fittings Produced from Polyethylene (PE) materials with Minimum Required Strength (MRS) Designation

1.5 The following precautionary caveat pertains only to the test method portion, Section 6, of this specification. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

[1] This specification is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.60 on Gas.

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2. Referenced Documents

2.1 *ASTM Standards:* [2]

2.1.1 *Terminology:*

D 1600 for Abbreviated Terms Relating to Plastics

F 412 Relating to Plastic Piping Systems

2.1.2 *Test Methods for:*

D 638 Tensile Properties of Plastics

D 1238 Melt Flow Rates of Thermoplastics by Extrusion Plastometer

D 1598 Time-to-Failure of Plastic Pipe Under Constant Internal Pressure

D 1599 Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings

D 2122 Determining Dimensions of Thermoplastic Pipe and Fittings

D 2290 Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe by Split Disk Method

D 2837 Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials

F 1473 Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipes and Resins

2.1.3 *Practices for:*

D 543 Evaluating the Resistance of Plastics to Chemical Reagents

D 618 Conditioning Plastics for Testing

D 1898 Sampling of Plastics

D 2657 Heat Fusion Joining of Polyolefin Pipe and Fittings

D 2774 Underground Installation of Thermoplastic Pressure Piping

2.1.4 *Specification for:*

F 1563 Tools to Squeeze-off Polyethylene (PE) Gas Pipe or Tubing

F 2138 Excess Flow Valves for Natural Gas Service

2.2 *ANSI Standards:*

B 16.40 Manually Operated Thermoplastic Gas Shutoffs and Valves in Gas Distribution Systems[3]

B 31.8 Gas Transmission and Distribution Piping Systems[3]

2.3 *Federal Specifications:*

Fed. Std. No. 123 Marking for Shipment (Civil Agencies)[4]

OPS Part 192 Title 49, Code of Federal Regulations[4]

2.4 *Military Standards:*

MIL-STD-129 Marking for Shipment and Storage[4]

MIL-STD-1235 (ORD) Single- and Multi-Level Continuous Sampling Procedures and Tables for Inspection by Attributes

2.5 *Other Documents:*

National Fire Protection Association: NFPA 58, Storage and Handling Liquefied Petroleum Gases[5]

PPI TR-33, Generic Butt Fusion Joining for Polyethylene Gas Pipe[6]

PPI TR-41, Generic Saddle Fusion Joining Procedure for Polyethylene Gas Piping[6]

3. Terminology

3.1 *Definitions*—Definitions are in accordance with Terminology F 412, and abbreviations are in accordance with Terminology D 1600, unless otherwise specified.

3.2 The gas industry terminology used in this specification is in accordance with ANSI B31.8 or 49 CFR Part 192, unless otherwise indicated.

3.3 The term *pipe* used herein refers to both pipe and tubing unless specifically stated otherwise.

3.4 *re-rounding equipment*—equipment used to reform the pipe and permanently reduce ovality to 5% or less.

3.5 *rounding equipment*—equipment, devices, clamps, and so forth, used to temporarily hold the pipe round while out-of-roundness measurements are made, or a joining procedure (heat fusion, electrofusion, or mechanical) is performed.

3.6 *standard thermoplastic material designated code* —the pipe material designation code shall consist of the abbreviation for the type of plastic (PE, PVC, or PA) followed by Arabic numerals which describe the short term properties in accordance with

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards*, Vol 08.01. volume information, refer to the standard's Document Summary page on the ASTM website.

Annual Book of ASTM

[3] Available from American National Standards, Vol 08.04. Institute, 1430 Broadway, New York, NY 10018.

[4] Discontinued; see *1997 Annual Book of ASTM Standards* , Vol 08.01.

[4] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111 – 5094, Attn: NPODS.

[5] Available from American National Standards Institute, 1430 Broadway, New York, NY 10018.

[5] National Fire Protection Association, 470 Atlantic Avenue, Boston, MA 02210.

[6] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111 – 5094, Attn: NPODS.

[6] Plastic Pipe Institute, Inc., 1825 Connecticut Avenue NW, Suite 680, Washington, DC 20009

applicable ASTM standards, the hydrostatic design stress for water at 73.4°F (23°C) in units of 100 psi with any decimal figures dropped. Where the hydrostatic design stress code contains less than two figures, a zero is used before the number. Thus, a complete material designation code shall consist of two or three letters and four figures for plastic pipe materials. For example, PE 2406 is a grade P24 polyethylene with a 630 psi design stress for water at 73.4°F (23°C). The hydrostatic design stresses for gas are not used in this designation code.

3.7 *thermoplastic pipe dimension ratio (DR)*—the ratio of pipe diameter to wall thickness. It is calculated by dividing the specified outside diameter of the pipe, in inches, by the minimum specified wall thickness, in inches. The standard dimension ratio (SDR) is a common numbering system which is derived from the ANSI preferred number series R 10.

3.8 *toe-in*—a small reduction of the outside diameter at the cut end of a length of thermoplastic pipe.

4. Materials

4.1 *General*—The plastic used to make pipe and fittings shall be virgin plastic or reworked plastic (see 4.2) as specified in the Annexes and shall have a Plastics Pipe Institute (PPI) long-term hydrostatic design stress and hydrostatic design basis rating.

4.2 *Rework Material*—Clean rework material of the same commercial designation, generated from the manufacturer's own pipe and fitting production shall not be used unless the pipe and fitting produced meet all the requirements of this specification.

NOTE 1—References and material descriptions for ABS, CAB, PB, PE2306, PE3306 and PE3406 have been removed from D 2513. Elimination of these materials does not affect the pipelines that are in service. They can still be used for gas distribution. The main reason for removing these materials from this standard is to reflect the current state of the art in gas distribution plastic piping.

5. Requirements

5.1 *General*—See the annexes for specific product requirements in addition to the following. Pipe shall be supplied in either coils or straight lengths. Any pipe supplied in coils must meet the same requirements before and after coiling.

5.2 *Workmanship*—The pipe and fittings shall be homogeneous throughout and free of visible cracks, holes, foreign inclusion, blisters, and dents, or other injurious defects. The pipe and fittings shall be as uniform as commercially practicable in color, opacity, density, and other physical properties.

5.3 *Pipe and Tubing Dimensions and Tolerances*:

5.3.1 *Dimension*—The dimensions shall be specified by wall thickness and outside diameter.

5.3.1.1 *Diameters*—The outside diameter shall meet the requirements given in Table 1 or Table 2 when measured in accordance with 6.5.

5.3.1.2 *Toe-In*—When measured in accordance with 6.5.1.1, the outside diameter at the cut end of the pipe shall not be more than 1.5 % smaller than the undistorted outside diameter. Measurement of the undistorted outside diameter shall be made no closer than 1.5 pipe diameters or 11.8 in. (300 mm), whichever distance is less, from the cut end of the pipe. Undistorted outside diameter shall meet the requirements of Table 1 or Table 2.

5.3.1.3 *Wall Thickness*—The wall thickness shall be as specified in Table 2 or Table 3 when measured in accordance with 6.5.1.2. The minimum wall thickness at any point of measurement shall be not less than the minimum wall thickness specified in Table 2 or Table 3.

5.3.1.4 *Wall Thickness Eccentricity Range*— The wall thickness eccentricity range shall be within 12 % when measured in accordance with 6.5.1.3.

5.3.1.5 *Ovality*—The ovality (cross section) of 3 in. IPS (88.9 mm) and smaller pipe shall not exceed 5 % when measured in accordance with 6.5.3. Measurements of coiled pipe shall be made on a sample cut from the coil, and in case of disagreement, conditioned per 6.3.

TABLE 1 Outside Diameters and Tolerances for Plastic Pipe, in. (mm)

Nominal Pipe Size	Outside Diameter	Tolerance	Maximum Out-of-Roundness			
			SDR 32.5	SDR 26	SDR 21	SDR 17 SDR 13.5 SDR 11
½	0.840 (21.3)	±0.004 (±0.102)	...	...	0.03(0.762)	0.016(0.406)
¾	1.050 (26.7)	±0.004 (±0.102)	...	...	0.03(0.762)	0.02(0.508)
1	1.315 (33.4)	±0.005 (±0.127)	...	...	0.03(0.762)	0.02(0.508)
1¼	1.660 (42.1)	±0.005 (±0.127)	...	...	0.03(0.762)	0.024(0.61)
1½	1.900 (48.3)	±0.006 (±0.152)	...	...	0.06(1.524)	0.024(0.61)
2	2.375 (60.3)	±0.006 (±0.152)	...	...	0.06(1.524)	0.024(0.61)
2½	2.875 (73.0)	±0.007 (±0.179)	...	...	0.06(1.524)	0.03(0.762)
3	3.500 (88.9)	±0.008 (±0.203)	...	...	0.06(1.524)	0.03(0.762)
3½	4.000 (101.6)	±0.008 (±0.203)	...	...	0.1(2.5)	0.03(0.762)
4	4.500 (114.3)	±0.009 (±0.229)	...	...	0.1(2.5)	0.03(0.762)
5	5.563 (141.3)	±0.010 (±0.254)	...	...	0.1(2.5)	0.06(1.524)
6	6.625 (168.3)	±0.011 (±0.279)	0.12(3)	0.11(2.74)	0.1(2.5)	0.07(1.778)
8	8.625 (219.1)	±0.013 (±0.330)	0.24(6.1)	0.16(4.06)	0.12(3)	0.08(2.04)
10	10.750 (273.0)	±0.015 (±0.381)	0.24(6.1)	0.2(5.08)	0.14(3.58)	0.1(2.5)
12	12.750 (323.8)	±0.017 (±0.432)	0.28(7.12)	0.2(5.08)	0.14(3.58)	0.1(2.5)

TABLE 2 Plastic Tubing-Diameters, Wall Thicknesses, and Tolerances, in. (mm)

Nominal Tubing Size (CTS)	Outside Diameter	Tolerance	Minimum Wall Thickness	Wall Thickness Tolerance
¼	0.375 (9.52)	±0.004 (±0.10)	0.062 (1.58)	+0.006 (+0.15)
⅜	0.500 (12.7)	±0.004 (±0.10)	0.062 (1.58)	+0.006 (+0.15)
½	0.625 (15.9)	±0.004 (±0.10)	0.062 (1.58)	+0.006 (+0.15)
½	0.625 (15.9)	±0.004 (±0.10)	0.090 (2.27)	+0.009 (+0.23)
½	0.625 (15.9)	±0.004 (±0.10)	0.104 (2.64)	+0.010 (+0.25)
¾	0.875 (22.2)	±0.004 (±0.10)	0.062 (1.58)	+0.006 (+0.15)
¾	0.875 (22.2)	±0.004 (±0.10)	0.077 (1.95)	+0.008 (+0.20)
¾	0.875 (22.2)	±0.004 (±0.10)	0.090 (2.27)	+0.009 (+0.23)
1	1.125 (28.6)	±0.005 (±0.13)	0.062 (1.58)	+0.007 (+0.18)
1	1.125 (28.6)	±0.005 (±0.13)	0.090 (2.27)	+0.011 (+0.28)
1	1.125 (28.6)	±0.005 (±0.13)	0.099 (2.51)	+0.012 (+0.31)
1	1.125 (28.6)	±0.005 (±0.13)	0.101 (2.56)	+0.012 (+0.31)
1	1.125 (28.6)	±0.005 (±0.13)	0.121 (3.07)	+0.015 (+0.38)
1¼	1.375 (34.9)	±0.005 (±0.13)	0.062 (1.58)	+0.007 (+0.18)
1¼	1.375 (34.9)	±0.005 (±0.13)	0.090 (2.27)	+0.011 (+0.28)
1¼	1.375 (34.9)	±0.005 (±0.13)	0.121 (3.07)	+0.015 (+0.38)
1¾	1.875 (47.6)	±0.006 (±0.15)	0.062 (1.58)	+0.007 (+0.18)

NOTE 2—Other factors, that is, installation compaction, static soil loading, and dynamic vehicular loads may increase the ovality; therefore, 5 % was chosen as the limit for the amount contributed by manufacturing, packing, in-plant storage, and shipping. For further information, see **(1)**.[7]

(1) Before or during installation, coiled pipe larger than 3 in. IPS (88.9 mm) shall be processed by the installer through re-rounding equipment that corrects ovality to 5% or less.

NOTE 3—Ovality is a packaging condition that occurs when roundable pipe is wound into a coil—the pipe flattens out as it is coiled. Ovality is corrected when joining equipment is applied to roundable pipe, or by field processing roundable pipe through re-rounding and straightening equipment during installation.

5.3.1.6 *Length*—The pipe shall be supplied in straight lengths or coils as agreed upon between the manufacturer and the purchaser. The length shall not be less than the minimum length agreed upon when corrected to 73°F (23°C).

5.3.1.7 When sizes other than those listed in Table 1, Table 2, or Table 3 are used, tolerances shall be: for outside diameter, use same tolerance of next smaller size; for wall thickness, use same tolerance percentage as shown in the tables.

5.3.2 *Fittings*—Fittings shall meet the requirements given in the applicable Annex.

5.4 *Chemical Resistance*—The pipe and fittings shall not increase in weight more than 0.5 % (1.0 % for toluene in methanol). Where the test specimen is a pipe ring, the material shall not change more than ±12 % in apparent tensile yield strength when measured in accordance with 6.9. Where the test specimen is a plaque, the material shall not change more than ±12 % in tensile strength at yield when measured in accordance with Test Method D 638. See Annex A5 for specific requirements for polyamide pipe.

NOTE 4—This pipe test is only an indication of what will happen as a result of short term exposure to these chemicals. For longterm results, additional testing is required.

5.5 *Sustained Pressure*—The pipe, fittings, or systems shall not fail as defined in Test Method D 1598, when tested in accordance with 6.6.

5.6 *Elevated Temperature Service*—Plastic piping materials intended for use at temperatures above 100°F (38°C) shall have the PPI hydrostatic design basis (HDB) determined at the specific temperature in accordance with Test Method D 2837. The 100 000-h intercept (long-term strength) shall be categorized in accordance with Table 4 and be listed as the "hydrostatic design basis of XXX psi at XXX °F (C°) for (compound name)."

NOTE 5—Many design factors for elevated temperature service cannot be covered in this specification. Users should consult applicable codes for limitations on pertinent maximum temperatures.

NOTE 6—In the absence of an HDB established at the specified temperature, the HDB of a higher temperature may be used in determining a design pressure rating at the specified temperature by arithmetic interpolation.

TABLE 3 Wall Thicknesses and Tolerances for Plastic Pipe, in (mm)[A,B]

Nominal Pipe Size (IPS)	DR[C]	Minimum	Tolerance
½	[D]	0.062 (1.58)	+0.007 (+0.178)

[7] National Fire Protection Association, 470 Atlantic Avenue, Boston, MA 02210.

[7] The boldface numbers in parentheses refer to the list of references at the end of this standard.

TABLE 3 *Continued*

Nominal Pipe Size (IPS)	DR[C]	Minimum	Tolerance
	11.0	0.076 (1.93)	+0.009 (+0.229)
	9.33	0.090 (2.29)	+0.011 (+0.279)
¾	[D]	0.090 (2.29)	+0.011 (+0.279)
	11.0	0.095 (2.41)	+0.011 (+0.279)
	Sch 40	0.113 (2.87)	+0.014 (+0.356)
1	[D]	0.090 (2.29)	+0.011 (+0.279)
	13.5	0.097 (2.46)	+0.012 (+0.305)
	11.0	0.120 (3.05)	+0.014 (+0.356)
	9.9	0.133 (3.38)	+0.016 (+0.406)
	9.33	0.140 (3.56)	+0.017 (+0.432)
1¼	[D]	0.090 (2.29)	+0.011 (+0.279)
	17.0	0.098 (2.49)	+0.012 (+0.305)
	13.5	0.123 (3.12)	+0.015 (+0.381)
	Sch 40	0.140 (3.56)	+0.017 (+0.432)
	11.0	0.151 (3.84)	+0.018 (+0.457)
	10.0	0.166 (4.22)	+0.020 (+0.508)
	9.33	0.178 (4.52)	+0.021 (+0.533)
	6.0	0.277 (7.04)	+0.033 (+0.838)
1½	[D]	0.090 (2.29)	+0.011 (+0.279)
	17	0.112 (2.85)	+0.013 (+0.330)
	13.5	0.141 (3.58)	+0.017 (+0.432)
	Sch 40	0.145 (3.68)	+0.017 (+0.432)
	11	0.173 (4.39)	+0.021 (+0.533)
2	21	0.113 (2.87)	+0.014 (+0.356)
	17	0.140 (3.56)	+0.017 (+0.432)
	Sch 40	0.154 (3.91)	+0.018 (+0.457)
	13.5	0.176 (4.47)	+0.021 (+0.533)
	11	0.216 (5.49)	+0.026 (+0.660)
	9.33	0.255 (6.48)	+0.031 (+0.787)
2½	21	0.137 (3.48)	+0.016 (+0.406)
	17	0.169 (4.29)	+0.020 (+0.508)
	13.5	0.213 (5.41)	+0.026 (+0.660)
	11	0.261 (6.63)	+0.031 (+0.787)
3	21	0.167 (4.24)	+0.020 (+0.508)
	17	0.206 (5.23)	+0.025 (+0.635)
	Sch 40	0.216 (5.49)	+0.026 (+0.660)
	13.5	0.259 (6.58)	+0.031 (+0.787)
	11.5	0.304 (7.72)	+0.036 (+0.914)
	11	0.318 (8.08)	+0.038 (+0.965)
	9.33	0.375 (9.53)	+0.045 (+1.143)
3½	21	0.190 (4.83)	+0.023 (+0.584)
	17	0.236 (5.99)	+0.028 (+0.711)
	13.5	0.296 (7.52)	+0.036 (+0.914)
	11	0.363 (9.22)	+0.044 (+1.118)
4	21	0.214 (5.44)	+0.026 (+0.660)
	19	0.237 (6.02)	+0.028 (+0.711)
	17	0.265 (6.73)	+0.032 (+0.813)
	13.5	0.333 (8.46)	+0.040 (+1.016)
	11.5	0.391 (9.93)	+0.047 (+1.194)
	11.0	0.409 (10.39)	+0.049 (+1.246)
	9.33	0.482 (12.24)	+0.058 (+1.473)
5	21.6	0.258 (6.55)	+0.031 (+0.787)
	21	0.265 (6.73)	+0.032 (+0.813)
	17	0.327 (8.31)	+0.039 (+0.991)
	13.5	0.412 (10.46)	+0.050 (+1.270)
	11	0.506 (12.85)	+0.061 (+1.549)
6	32.5	0.204 (5.18)	+0.024 (+0.610)
	26	0.255 (6.48)	+0.031 (+0.787)

TABLE 3 *Continued*

Nominal Pipe Size (IPS)	DR[C]	Minimum	Tolerance
	23.7	0.280 (7.11)	+0.034 (+0.864)
	21	0.315 (8.00)	+0.038 (+0.965)
	17	0.390 (9.91)	+0.047 (+1.194)
	13.5	0.491 (12.47)	+0.059 (+1.499)
	11.5	0.576 (14.63)	+0.069 (+1.753)
	11.0	0.602 (15.29)	+0.072 (+1.829)
8	32.5	0.265 (6.73)	+0.032 (+0.813)
	26	0.332 (8.43)	+0.040 (+1.016)
	21	0.411 (10.44)	+0.049 (+1.245)
	17	0.507 (12.90)	+0.061 (+1.549)
	13.5	0.639 (16.23)	+0.077 (+1.956)
	11.5	0.750 (19.05)	+0.090 (+2.286)
	11	0.784 (19.91)	+0.094 (+2.388)
10	32.5	0.331 (8.41)	+0.040 (+1.016)
	26	0.413 (10.49)	+0.050 (+1.270)
	21	0.512 (13.00)	+0.061 (+1.549)
	17	0.632 (16.05)	+0.076 (+1.930)
	13.5	0.796 (20.22)	+0.096 (+2.438)
	11.5	0.935 (23.75)	+0.112 (+2.845)
	11	0.977 (24.82)	+0.117 (+2.972)
12	32.5	0.392 (9.96)	+0.047 (+1.194)
	26	0.490 (12.45)	+0.059 (+1.499)
	21	0.607 (15.42)	+0.073 (+1.854)
	17	0.750 (19.05)	+0.090 (+2.286)
	13.5	0.944 (23.98)	+0.113 (+2.870)
	11.5	1.109 (28.17)	+0.133 (+3.378)
	11	1.159 (29.44)	+0.139 (+3.531)

[A] The sizes listed in Table 3 are those commercially available sizes used by the gas industry.

[B] The minimum is the lowest wall thickness of the pipe at any cross section. The maximum permitted wall thickness, at any cross section, is the minimum wall thickness plus the stated tolerance. All tolerances are on the plus side of the minimum requirement.

[C] The DR shown are designations commonly accepted by the gas industry and do not calculate exactly.

[D] These wall thicknesses are minimum and are not a function of the dimension ratios.

TABLE 4 Pipe Category

Property	Test Method	Category						
		A	B	C	D	E	F	G
Temperature, °F (°C)	. . .	100 (38)	120 (49)	140 (60)	160 (71)	180 (82)	. . .	. . .
Hydrostatic Design Basis, psi (MPa)	D 2837	400 (2.8)	500 (3.4)	630 (4.3)	800 (5.5)	1000 (6.9)	1250 (8.6)	1600 (11.0)
Melt Index[A]	D 1238	>0.5	0.2–0.5	0.01–0.3	<0.01[B]	[C]	. . .	. . .

Examples: CDB - At 140ºF (60ºC) the HDB is 800 psi (5.5 MPa). The approximate melt index range is 0.2 to 0.5 g/10 min for this PE pipe.
DF - At 160ºF (71ºC) the HDB is 1250 psi (8.6 MPa)[A].

[A] The melt Index information in this table is intended to provide guidance relating to heat fusion joining of PE materials, not for classification of materials. This property is not applicable to non-PE materials or to mechanical fittings. See 7.3.

[B] Typically melt flow measured under condition 190/21.6 is less than 4.01 g/10 min.

[C] When a PE pipe or fitting is marked per 7.2 or 7.3 with the letter "E", it affirms that the manufacturer has verified the applicability of generic fusion joining with their products in accordance with PPI TR-33 and PPI TR-41 by joining to itself and to other "E" materials and testing the joints in accordance with applicable regulations. However, qualification of joining procedures by operators in accordance with applicable regulations may still be required. Information about manufacturers who have verified PPI TR-33 and PPI TR-41 generic fusion joining with their products is found in PPI TR-33 and PPI TR-41. Consult PPI and the manufacturer for additional information.

5.7 *Minimum Hydrostatic Burst Pressure* —The burst requirements for plastic pipe shall be as given in the appropriate annexes.

5.8 *Apparent Tensile Strength At Yield*— The minimum apparent tensile strengths at yield for plastic pipe are given in the annexes when determined in accordance with 6.8.

5.9 *Joints*:

5.9.1 *Solvent Cemented*—Joints of solvent cementable pipe and fittings shall be made in accordance with the user's written procedure.

5.9.2 *Heat Fusion*:

5.9.2.1 Heat fusion joints of thermoplastic pipe and fittings shall be made in accordance with Practice D 2657 and the user's written procedure.

5.9.2.2 PE butt fusion joining shall be between components (pipes, fittings, or valves) having the same SDR or DR. Butt fusion between unlike SDR or DR components shall be allowed only if it has been demonstrated that long term performance is not

adversely affected. The minimum requirement to demonstrate long term performance shall be the validation procedure for PE in Test Method D 2837. The Hydrostatic Design Basis (HDB) of the PE material shall be validated using specimens containing butt fusion joints resulting from different SDRs or DRs. Pipe/pipe joints of the given PE material that pass shall validate pipe/pipe, pipe/fitting, or fitting/fitting joints of the same SDR ratio for that PE material.

5.9.3 *Mechanical*—Mechanical fittings shall be installed in accordance with the user's written procedures and the fitting manufacturer's installation instructions. The joint shall be tested in accordance with the specific design category as outlined in 6.10.

5.10 *Plastic Valves*—All plastic gas valves shall meet the requirements of ANSI Standard B 16.40.

5.11 *Excess Flow Valves*—All excess flow valves shall meet the requirements of Specification F 2138.

6. Test Methods

6.1 *General*—The test methods in this specification cover plastic pipe and fittings to be used for gas distribution. Test methods that are applicable from other specifications will be referenced in the paragraph pertaining to that particular test.

6.2 *Sampling*—Take a representative sample of the pipe and fittings sufficient to determine conformance with this specification. About 40 ft (12 m) of pipe is required to perform all the tests prescribed. The number of fittings required varies, depending upon the size and type of fitting. A sampling plan shall be agreed upon by the purchaser and the manufacturer (see Practice D 1898).

6.2.1 *Pipe Test Specimens*—Not less than 50 % of the test specimens required for any pressure test shall have at least a part of the marking in their central sections. The central section is that portion of pipe which is at least one pipe diameter away from an end closure.

6.3 *Conditioning*—Unless otherwise specified, condition the specimens prior to test at 73.4 ± 3.6°F (23 ± 2°C) and 50 ± 5 % relative humidity for not less than 40 h, in accordance with Procedure A of Practice D 618 for those tests where conditioning is required and in all cases of disagreement.

6.4 *Test Conditions*—Conduct the test in the standard laboratory atmosphere of 73.4 ± 3.6°F (23 ± 2°C) and 50 ± 5 % relative humidity, unless otherwise specified.

6.5 *Dimensions and Tolerances*:

6.5.1 *Pipe*—Any length of pipe is used to determine the dimensions. Coiled pipe shall be measured in the natural springback condition, unless specified otherwise.

6.5.1.1 *Diameter*—Measure the diameter of the pipe in accordance with Test Method D 2122. The average outside diameter for nonroundable pipe is the arithmetic average of the maximum and minimum diameters at any cross section on the length of the pipe. For roundable pipe, out-of-roundness tolerance applies to measurements made while the pipe is rounded with the manufacturer's recommended equipment. Measure out-of-roundness within one-half pipe diameter or 2 in. (50 mm), whichever is closer, of the rounding equipment. See Test Method D 2122 for definitions of nonroundable and roundable pipe.

(1) The pipe surface shall be free of gross imperfections such as, deep scratches, grooves, or high or low (flat) spots around the pipe circumference.

NOTE 7—Excessive out-of-roundness may be caused by manufacturing irregularities around the circumference of the pipe, such as deep scratches, gouges, flat spots, and high spots. Such defects could detrimentally affect joining. To simulate field joining of roundable pipe, out-of-roundness is checked by fitting a rounding device on the pipe, then measuring diameter.

6.5.1.2 *Wall Thickness*—Make a minimum of six measurements at each cross section in accordance with Test Method D 2122.

6.5.1.3 *Wall Thickness Eccentricity Range*— Measure in a manner such that the maximum, *A*, and the minimum, *B*, wall thickness at single points of each cross section measured are obtained. Calculate the wall thickness eccentricity range, *E*, in percent for each cross section as follows:

$$E = [(A - B)/A] \times 100 \quad (1)$$

6.5.1.4 *Length*—Measure pipe length and other linear dimensions with a steel tape or other device, accurate to ±1/32 in. (±1 mm) in 10 ft (3 m).

6.5.2 *Fittings*—Measure the dimensions of fittings in accordance with Test Method D 2122.

6.5.3 *Ovality*:

6.5.3.1 *Apparatus*—A micrometer or vernier caliper accurate to within ±0.001 in. (±0.02 mm).

6.5.3.2 *Procedure*—Take a series of outside diameter (OD) measurements at closely spaced intervals around the circumference to ensure that the minimum and maximum diameters have been determined.

6.5.3.3 *Calculation*—Calculate the percent ovality as follows:

$$\%\ \text{ovality} = \frac{\text{maximum OD} - \text{minimum OD}}{\text{minimum OD} + \text{maximum OD}} \times 200 \quad (2)$$

6.6 *Sustained Pressure Test*:

6.6.1 Select six test specimens of pipe or fittings at random, condition at the standard laboratory test temperature and humidity, and pressure test in accordance with Test Method D 1598.

6.6.1.1 Test specimens shall be prepared so that the minimum length of pipe on each side of the fitting is equal to 5 times the diameter of the pipe but in no case less than 12 in. (304 mm) for sizes less than 6 in. For sizes 6 in. and larger, the minimum length shall be equal to 3 times the diameter or 30 in. (762 mm), whichever is shorter.

6.6.1.2 Pressures used shall be as shown in the annexes or as calculated (using the pipe's actual measured minimum wall thickness, outside diameter, and the applicable fiber stress shown in the annexes), whichever is greater. Piping intended for use at temperatures of 100°F (38°C) and higher shall be tested at both 73°F (23°C) and the maximum design temperature. The test fiber stress shall be the hydrostatic design basis (HDB) or 80 % of the 100 000-h intercept of the material, whichever is greater.

NOTE 8—Air, methane, or nitrogen may be substituted for water as the test medium.

6.6.2 Maintain the specimens at the pressures required, held to ±10 psi (0.07 MPa), for a period of 1000 h at the test temperature ±3.6°F (±2°C) as specified in 6.6.1.

6.6.3 Failure of two of the six specimens tested shall constitute failure in the test. Failure of one of the six specimens tested is cause for retest of six additional specimens. Failure of one of the six specimens in retest shall constitute failure in the test. Evidence of failure of the pipe shall be as defined in Test Method D 1598.

6.7 *Minimum Hydrostatic Burst Pressure (Quick Burst)* —The test equipment, procedures, and failure definitions shall be as specified in Test Method D 1599 and the annexes. Pressures shall be as shown in the Annexes or as calculated (using the pipe's actual measured minimum wall thickness, outside diameter, and the applicable fiber stress), whichever is greater.

6.8 *Apparent Tensile Properties*—The procedure and test equipment shall be as specified inTest Method D 2290, Procedure B. The speed of testing shall be 0.5 in. (12.7 mm)/min. Cut "ring" specimens from pipe. They shall be ½-in. (12.7 mm) wide with a ¼-in. (6.3-mm) wide reduced section. Test a minimum of five specimens. This method is applicable to all pipe of nominal ¾-in. (19.0-mm) outside diameter and larger.

6.9 *Chemical Resistance*—Determine the resistance to the following chemicals in accordance with Test Method D 543. Where available, the test specimen shall be a ring 2 in. SDR 11 pipe cut to the ring dimensions specified in 6.8. For materials that are not readily available as 2 in. SDR 11 pipe, the test specimen shall be a plaque of material ¼ by 2 by 4 in. (6.3 by 50.8 by 101.6 mm) with a 1 in. (25.4 mm) wide reduced section.

Chemicals	Concentration (% by volume)
Mineral oil (USP)	100
Tertiary-butyl mercaptan	5 in mineral oil
Antifreeze agents (at least one shall be used):	
Methanol, or	100
Ethylene glycol	100
Toluene	15 in methanol

Test five specimens with each chemical. Weigh the specimens to the nearest 0.005 g and completely immerse them in the chemicals for 72 h. On removal from the chemicals, wipe the specimens with a clean dry cloth. Condition in air for 2 to 2¼ h and reweigh. Calculate the increase in weight to the nearest 0.01 % on the basis of initial weight. Test the specimen in tension in accordance with 6.8 within ½ h after weighing. Examine the weight and apparent tensile strength of each specimen for conformance to the requirement in 5.4. (**Warning—**Because of the possible toxicity of these reagents, refer to the Material Safety Data Sheet on each of these reagents before using or handling them.)

6.10 *Categorization of Mechanical Joints*—The following test methods provide a uniform procedure for qualification or categorization of mechanical joints using short term pullout resistance tests and burst tests. The mechanical joint categories and test methods are as follows:

6.10.1 *Category 1*—A mechanical joint design that provides a seal plus a resistance to a force on the pipe end equal to or greater than that which will cause a permanent deformation of the pipe.

6.10.1.1 The apparatus and report shall be as specified in Test Method D 638. The test shall be conducted at ambient temperatures, that is, 67 ± 10°F (19.4 ± 5.6°C). The speed of the testing shall be 0.2 in. (5 mm)/min ±25 %. Five specimens shall be prepared following the manufacturer's published installation instructions. Length of the specimens shall be such that the unreinforced distance between the grip of the apparatus and the end of the stiffener is at least five times the nominal outside diameter of the pipe size being tested. Apply a load until permanent deformation (yield) occurs in the unreinforced area of the piping.

6.10.1.2 Results obtained from the above method pertain only to the specific outside diameter, wall thickness, and compound of the piping used in the test and specific fitting design tested.

NOTE 9—The ability to restrain pipe to its yield as specified above does not guarantee that a properly installed joint will prevent pullout under actual long-term field conditions. Joints that cannot pass this test would be expected to pullout under actual long term field conditions. To date, this test is the best available for disqualifying unsound joints.

6.10.2 *Category 2*—A mechanical joint design that provides a seal only (see Appendix X2.5.5). A mechanical joint designed for this category excludes any provisions in the design or installation of the joint to resist any axial pullout forces; therefore, tensile tests are not required.

6.10.2.1 The test assembly shall meet the burst test requirements of 5.7 when tested in accordance with Test Method D 1599 with end closures designed in accordance with Test Method D 1599.

6.10.3 *Category 3*—A mechanical joint design that provides a seal plus a pipe restraint rating equivalent to the anticipated thermal stresses occurring in a pipeline (see Appendix X2.4). This category has a manufacturer's rated pipe end restraint less than the value required to yield the pipe as outlined in 6.10.1 (Category 1).

6.10.3.1 The procedures and testing shall be the same as outlined in 6.10.1 (Category 1) except the test tensile values shall meet

the rated values published by the mechanical fitting manufacturer.

7. Marking

7.1 *Pipe*—All required marking shall be legible, visible, and permanent. To ensure permanence, marking shall be applied so it can only be removed by physically removing part of the pipe wall. The marking shall (1) not reduce the wall thickness to less than the minimum value for the pipe, (2) not have any effect on the long-term strength of the pipe, and (3) not provide leakage channels when elastomeric gasket compression fittings are used to make the joints. These marking shall consist of the word GAS, the designation ASTM D 2513, the manufacturer's name or trademark, the normal pipe size including the sizing system used (IPS, CTS, or OD), DR or minimum wall thickness, material designation, and date of manufacture.

7.1.1 In addition to 7.1, the pipe marking shall include a coding that will enable the manufacturer to determine the location of manufacture, pipe production and resin lots, and any additional information which is agreed upon between the manufacturer and purchaser. The manufacturer shall maintain such records for fifty years or for the design service life of the pipe, whichever is longer.

7.1.2 All the markings in 7.1 and 7.1.1 shall be repeated at intervals not exceeding 5 ft (1.5 m). For indented printing, either the indented print line shall be in a color that contrasts with that of the pipe, or a separate print line shall be in a color that contrasts with the pipe. See Annex A1 and Annex A2 for additional specific marking requirements. When color is applied to identify gas service, such as with color stripes, a color shell or solid color pipe, yellow color shall be used.

NOTE 10—Using color to identify piping service is not mandatory, but if used, yellow color is required.

7.2 Pipe intended for natural gas service at elevated temperatures greater than 73°F (23°C) shall be marked with additional code letters from Table 4 (the first code letter to identify the temperature of pressure rating, the second code letter to identify HDB at highest rated temperature, and the third code letter to identify the melt index).

NOTE 11—The non-mandatory, preferred order for all the items required in the print line in the marking sections 7.1 and 7.2 are:
(1) Pipe size including sizing system (IPS, CTS or OD),
(2) SDR (DR) or minimum wall thickness,
(3) Manufacturer's name or trademark,
(4) GAS,
(5) Pipe material designation code,
(6) Elevated temperature code from Table 4,
(7) ASTM D 2513,
(8) Manufacturer's lot code (includes date of manufacture in some cases), and
(9) Additional information, including date of manufacture, coil number, sequential footage, third party certification mark etc.
Example: 2 in. IPS SDR 11 MANUFACTURER NAME GAS PE 2406 CEC ASTM D 2513 LOT CODE INFO 02JAN98 coil #506.

7.3 *Fittings*—Fittings shall be marked D 2513, as well as with the applicable fitting specification. All fittings shall be marked on the body or hub. The markings shall consist at least of the manufacturer's name or trademark, or both, the size, the symbol for the type of material, and the three-letter code from Table 4 (as described in Section 7.2). In addition, the fittings markings shall include code that will enable the manufacturer to determine the date of manufacture, the location of manufacture, fitting production and resin lots, and any additional information which may be agreed upon between the manufacturer and purchaser. The manufacturer shall maintain such records for 50 years or for the design service life of the fittings, whichever is longer.

NOTE 12—Section 7.3 is applicable to fusion type fittings only. The marking requirements in Section 7.3 are not applicable to mechanical fittings.

8. Quality Assurance

8.1 When the product is marked with this designation, D 2513, the manufacturer affirms that the product was manufactured, inspected, sampled, and tested in accordance with this specification and has been found to meet the requirements of this specification.

SUPPLEMENTARY REQUIREMENTS

GOVERNMENT/MILITARY PROCUREMENT

These requirements apply only to federal/military procurement, not domestic sales or transfers.

S1. *Responsibility for Inspection*—Unless otherwise specified in the contract or purchase order, the producer is responsible for performance of all inspection and test requirements specified herein. The producer shall use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless the purchaser disapproves. The purchaser shall have the right to perform any of the inspections and tests set forth in this specification where such inspections are deemed necessary to ensure that material conforms to prescribed requirements.

NOTE S00001—In U.S. federal contracts, the contractor is responsible for inspection.

S2. *Packaging and Marking for U.S. Government Procurement:*

S2.1 *Packaging* —Unless otherwise specified in the contract, the materials shall be packaged in accordance with the supplier's standard practices in a manner ensuring arrival at destination in satisfactory condition and which will be acceptable to the carrier at lowest rates. Containers and packing shall comply with Uniform Freight Classification rules or National Motor Freight Classification rules.

S2.2 *Marking*—Marking for shipment shall be in accordance with Fed. Std. No. 123 for civil agencies and MIL-STD 129 for military agencies.

NOTE S00002—The inclusion of U.S. Government procurement requirements should not be construed as an indication that the U.S. Government uses or endorses the products described in this specification.

ANNEXES

(Mandatory Information)

A1. SUPPLEMENTAL REQUIREMENTS FOR GAS PRESSURE PIPE AND FITTINGS PRODUCED FROM POLYETHYLENE (PE) MATERIAL

A1.1 Scope

A1.1.1 This annex covers requirements for PE pipe and fittings. These requirements are in addition to those in the main body of this specification.

NOTE A1.1—Because Table 1, which covers nominal pipe sizes up to 12 in. is in the body of this specification, and Table A1.1 is in Annex A1, the user should be aware of the larger tolerance allowed the larger pipe.

A1.2 Referenced Documents

A1.2.1 *ASTM Standards*: [2]

A1.2.1.1 *Test Methods for*:

D 1238 Melt Flow Rate of Thermoplastics by Extrusion Plastometers

A1.2.1.2 *Specification for*:

D 1248 Polyethylene Plastics Extrusion Materials for Wire and Cable

D 2683 Socket-Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing

D 3261 Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing

D 3350 Polyethylene Plastic Pipe and Fittings Materials

TABLE A1.1 Outside Diameters and Tolerances, 14 in. and Larger Pipe

Nominal Pipe Size	Actual Outside Diameters, in. (mm)	
	Average	Tolerance
14	14.000 (355.6)	±0.063 (±1.60)
16	16.000 (406.4)	±0.072 (±1.83)
18	18.000 (457.2)	±0.081 (±2.06)
20	20.000 (508.0)	±0.090 (±2.29)
22	22.000 (558.8)	±0.099 (±2.51)
24	24.000 (609.6)	±0.108 (±2.74)

F 1055 Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Pipe and Tubing

A1.2.2 *ISO Standards:*

ISO 4437 Buried polyethlene (PE) pipes for the supply of gaseous fuels-Metric series-Specifications[8]

ISO 11922-1 Thermoplastics pipes for the conveyance of fluids-Dimentsions and tolerances —Part 1: Metric series[8]

A1.3 Materials

A1.3.1 *Classification*—Polyethylene materials suitable for use in the manufacture of pipe and fittings under this specification shall be classified in accordance with Specification D 3350, and as shown in Table A1.2. *Example*: for a polyethylene material having an HDB of 1250 psi (8.6 MPa), Cell Class 3, the base resin density must have a cell classification of 2 or 3; the melt index classification must be 1, 2, 3, 4, 5, or 6; and so forth.

A1.3.2 *Short and Long Term Properties*— Polyethylene pipe and fittings shall be made from PE materials which also satisfy the combinations of short- and long-term property requirements shown in Table A1.3.

A1.3.3 *Hydrostatic Design Basis (HDB) Substantiation*—The HDB for PE materials at 73°F (23°C) shall be substantiated by showing that the extrapolation of the stress regression curve is linear to the 438 000-h intercept (long-term hydrostatic strength at 50 years in accordance with Test Method D 2837). This will be done in accordance with Test Method D 2837 using one of the two following procedures:

A1.3.3.1 Use the twelve data points from Conditions I and II obtained in 5.6.1 (Procedure I) of Test Method D 2837 along with the 438 000-h intercept to solve for the three-coefficient rate process extrapolation equation. Then using this new model, calculate the mean estimated failure time for Condition III. When the log average time for six specimens tested at Condition III has reached this time, linear extrapolation of the 73°F (23°C) stress regression curve to 438 000 h is substantiated.

A1.3.3.2 When 5.6.2 (Procedure II) of Test Method D 2837 is used to validate the 73°F (23°C) HDB, linear extrapolation of the stress regression curve to 438 000 h is substantiated when the log average failure time of the test specimens at 176°F (80°C) surpasses 6000 h.

NOTE A1.2—The long-term hydrostatic strength at 50 years in accordance with Test Method D 2837 is not to be used for any pressure rating calculations. The MAOP is still calculated using the HDB obtained from Test Method D 2837 long-term hydrostatic strength at 100 000 h.

A1.3.4 *Qualification for LPG Service*— Materials that qualify for natural gas service in accordance with A1.3.3 and that carry a recommended HDB for 140°F in accordance with 5.6, also qualify for LPG service without the need for further testing.

NOTE A1.3—The terms LPG and LPG gas are synonymous and only apply to a particular kind of fuel gas. For compositions and properties of LPG gases see NFPA 58, Appendix B.

A1.3.5 *Slow Crack Growth Resistance*— Test method is F 1473 on compression molded plaques. Stress is 2.4 MPa based on the unotched area. Temperature is 80°C. Notch depth in accordance with Table 1 in Test Method F 1473. The minimum of the average of the two tests shall be 100 h. Do at least four tests in case of a dispute.

A1.3.6 *Additive Classes*—PE materials shall be either Class B, with antioxidant and UV stabilizer, or C as defined in Specification D 1248, or Class C or E as defined in Specification D 3350.

A1.4 Fittings

A1.4.1 PE fittings intended for use with the corresponding sized outside-diameter PE pipe shall meet the requirements of Specification D 2683 for socket-type fittings, Specification D 3261 for butt-type fittings, or Specification F 1055 for electrofusion-type fittings and the requirements of this specification.

A1.5 Requirements for Pipe and Fittings

A1.5.1 *Conditioning*—For those tests where conditioning is required or unless otherwise specified, condition the specimens prior to testing for a minimum of 1 h in water or 4 h in air at 73.4 ± 3.6°F (23 ± 2°C) or in accordance with 6.3. The conditioning

[8] Plastic Pipe Institute, Inc., 1825 Connecticut Avenue NW, Suite 680, Washington, DC 20009

[8] Available from International Organization for Standardization 1 Rue de Varembé, Case Postale 56, CH-1211, Geneva 20, Switzerland

TABLE A1.2 Specification D 3350 Cell Classifications of Polyethylene Pipe and Fittings Materials

PE Material Designation Code:	PE 2406	PE 3408
Physical Properties:		
Density	2	3
Melt index	1, 2, 3, or 4	3, 4, or 5
Flexural modulus	3 or 4	4 or 5
Tensile strength	3 or 4	4 or 5
Slow crack growth resistance PENT	6	6
Hydrostatic design basis	3	4

TABLE A1.3 Short and Long Term Property Requirements

PE Material Designation Code	Short-Term in Accordance with D 3350	Long-Term in Accordance with D 2837[A]
PE 2406	Grade PE 24	HDB of 1250 psi for 73°F
PE 3408	Grade PE 34	HDB of 1600 psi for 73°F

[A] The hydrostatic design basis (HDB) shall be established using water or natural gas as the pressurizing fluid.

requirements of 6.3 shall be used in all cases of disagreement.

A1.5.2 *Minimum Hydrostatic Burst Pressure/Apparent Tensile Strength (Quick Burst)*—The pipe or system shall fail in a ductile manner when tested in accordance with Test Method D 1599. For pipe sizes above 4-in. nominal diameter, the testing lab shall be allowed to replace the quick burst test (Test Method D 1599) by the apparent ring tensile strength test (Test Method D 2290). The minimum apparent tensile strength at yield when determined in accordance with 6.8 shall be 2520 psi (17.4 MPa).

A1.5.3 *Sustained Pressure 73°F (23°C)*—The pipe or system shall not fail in less than 1000 h when tested in accordance with Test Method D 1598. For PE 2406 material, the stress shall be 1320 psi, for PE 3408 materials, the stress shall be 1600 psi.

A1.5.4 *Melt Index*—Melt index is the flow rate of PE material when measured in accordance with Test Method D 1238, condition 190/2.16 (formerly Condition E). Materials that record zero flow under condition 190/2.16 shall be measured in accordance with condition 190/21.6 (formerly condition F). The melt index of pipe/fitting shall meet the designated category in Table 4. The sample shall be representative of the cross section of the pipe or fitting and diced to an appropriate size by a method not producing heat.

A1.5.5 *Squeeze-Off*—This requirement is limited to pipe sizes, wall thicknesses, squeeze procedures, and conditions deemed suitable for squeeze-off in service by the pipe manufacturer. There shall be no leakage or visual evidence of splitting, cracking, breaking or reduction in 1000-h sustained pressure category when pipe is tested as follows:

A1.5.5.1 Prepare six randomly selected pipe specimens in accordance with Test Method D 1598 except they shall be unfilled.

A1.5.5.2 The squeeze-off shall be effected at the mid-point of the test specimen, 90° to the point of the measured minimum wall thickness. Close the squeeze bars to the gap stop in Specification F 1563 and hold in constraint for 4 h. Remove squeeze bars and reround pipe by closing squeeze bars at a point 90° from the squeeze area.

A1.5.5.3 Immediately upon removal of the squeeze-off tool, fill the specimens with ambient temperature water, that is, 67 ± 10°F (19.4 ± 5.6°C), condition, and test in accordance with 6.6.

A1.5.6 *Thermal Stability*—The PE material shall contain sufficient antioxidant so that the minimum induction temperature shall be 428°F (220°C) when tested in accordance with Specification D 3350. The sample shall be representative of the cross section of the pipe or fittings.

A1.5.7 *Outdoor Storage Stability*— PE pipe stored outdoors and unprotected for at least two years from date of manufacture shall meet all the requirements of this specification. PE pipe stored outdoors for over two years from date of manufacture is suitable for use if it meets the requirements of this specification.

A1.5.8 *Dimensions and Tolerances*— The outside diameter shall meet the requirements in Table 1 and Table 2 in the main body for sizes through 12 in., or in Table A1.1 for larger sizes or in Table A1.4 for metric sizes. The wall thickness shall meet the requirements in Table 2 and Table 3 in the main body for sizes through 12 in., or in Table A1.5 for larger sizes or in Table A1.4 for metric sizes. When sizes other than those listed in these tables are used, the tolerances of the next lower size shall be used.

A1.5.9 *Short Term Pressurization for Sizes Above 12 in.*—Pipe and molded or fabricated fittings shall not fail when tested in accordance with Test Method D 1599 with the hoop stress of 2500 psi for Class 2 density materials or 2900 psi for Class 3 density materials. Hoop stress calculation shall be based on the DR of the fitting at the point of fusion. (**Warning—**Pressurization of pipe specimens above 12 in. nominal diameter being tested in accordance with A1.5.8 should not commence until it is certain that all entrapped air has been bled from the water-filled specimens.)

NOTE A1.4—The requirements in A1.5.8 are for laboratory proof testing only and should not be interpreted as applicable to on-site testing for acceptance of installed systems larger than 12 in. See appropriate installation standards or manufacturer's recommendations for field test procedures.

A1.5.10 *HDB Validation for PE Pipe*— The 73°F (23°C) Hydrostatic Design Basis (HDB) of PE pipe shall be validated by the pipe producer using the PE validation procedure as outlined in Test Method D 2837. For PE 2406 materials, the HDB of 1250 psi shall be validated; for PE 3408 materials, the HDB of 1600 psi shall be validated.

A1.5.11 *Inside Surface Ductility for Pipe*—The inside surface of pipe shall be ductile as shown by testing in accordance with A1.5.11.1, A1.5.11.2, and A1.5.11.3. Before testing, specimens shall be conditioned in accordance with Practice D 618 for 40 h at 73.4 ± 3.6°F (23 ± 2°C) and 50 % relative humidity.

NOTE A1.5—ID ductility testing may also be conducted for quality control purposes, however, there is no known data that identifies one test as inferior, equal, or superior to the others, therefore, results from one test should not be evaluated against the results from either of the other two tests.

A1.5.11.1 *Bend-back Test Method*:

(*1*) From the pipe, squarely cut a ring of pipe with a minimum width of 1¼ in. (32 mm). The entire wall thickness may be tested, or material may be removed from the OD surface of the pipe, while maintaining an undisturbed ID surface, to produce a ring with ⅜-in. (9.5-mm) wall thickness.

TABLE A1.4 Outside Diameter and Wall Thickness for Metric Sizes[A]

Nominal	Average Outside Diameter				Maximum Out of Roundness[B]		DR 17.6 Wall Thickness				DR 11 Wall Thickness			
Size	minimum		maximum				minimum		maximum		minimum		maximum	
mm	mm	(in.)	mm	(in.)	mm	(in.)	mm	(in.)	mm	(in.)	mm	(in.)	mm	(in.)
16	16.0	(0.630)	16.3	(0.642)	1.2	(0.047)	2.3	(0.091)	2.7	(0.106)	3.0	(0.118)	3.5	(0.138)
20	20.0	(0.787)	20.3	(0.799)	1.2	(0.047)	2.3	(0.091)	2.7	(0.106)	3.0	(0.118)	3.5	(0.138)
25	25.0	(0.984)	25.3	(0.996)	1.2	(0.047)	2.3	(0.091)	2.7	(0.106)	3.0	(0.118)	3.5	(0.138)
32	32.0	(1.260)	32.3	(1.272)	1.3	(0.051)	2.3	(0.091)	2.7	(0.106)	3.0	(0.118)	3.5	(0.138)
40	40.0	(1.575)	40.4	(1.591)	1.4	(0.055)	2.3	(0.091)	2.7	(0.106)	3.7	(0.146)	4.2	(0.165)
50	50.0	(1.969)	50.4	(1.984)	1.4	(0.055)	2.9	(0.114)	3.3	(0.130)	4.6	(0.181)	5.2	(0.205)
63	63.0	(2.480)	63.4	(2.496)	1.5	(0.059)	3.6	(0.142)	4.1	(0.161)	5.8	(0.228)	6.5	(0.256)
75	75.0	(2.953)	75.5	(2.972)	1.6	(0.063)	4.3	(0.169)	4.9	(0.193)	6.8	(0.268)	7.6	(0.299)
90	90.0	(3.543)	90.6	(3.567)	1.8	(0.071)	5.2	(0.205)	5.9	(0.232)	8.2	(0.323)	9.2	(0.362)
110	110.0	(4.331)	110.7	(4.358)	2.2	(0.087)	6.3	(0.248)	7.1	(0.280)	10.0	(0.394)	11.2	(0.441)
125	125.0	(4.921)	125.8	(4.953)	2.5	(0.098)	7.1	(0.280)	8.0	(0.315)	11.4	(0.449)	12.7	(0.500)
140	140.0	(5.512)	140.9	(5.547)	2.8	(0.110)	8.0	(0.315)	9.0	(0.354)	12.7	(0.500)	14.1	(0.555)
160	160.0	(6.299)	161.0	(6.339)	3.2	(0.126)	9.1	(0.358)	10.2	(0.402)	14.6	(0.575)	16.2	(0.638)
180	180.0	(7.087)	181.1	(7.130)	3.6	(0.142)	10.3	(0.406)	11.5	(0.453)	16.4	(0.646)	18.2	(0.717)
200	200.0	(7.874)	201.2	(7.921)	4.0	(0.157)	11.4	(0.449)	12.7	(0.500)	18.2	(0.717)	20.2	(0.795)
225	225.0	(8.858)	226.4	(8.913)	4.5	(0.177)	12.8	(0.504)	14.2	(0.599)	20.5	(0.807)	22.7	(0.894)
250	250.0	(9.843)	251.5	(9.902)	5.0	(0.197)	14.2	(0.559)	15.8	(0.622)	22.7	(0.894)	26.1	(1.028)
280	280.0	(11.024)	281.7	(11.091)	9.8	(0.386)	15.9	(0.626)	17.6	(0.693)	25.4	(1.000)	28.1	(1.106)
315	315.0	(12.402)	316.9	(12.476)	11.1	(0.437)	17.9	(0.705)	19.8	(0.780)	28.6	(1.126)	31.6	(1.244)
355	355.0	(13.976)	357.2	(14.063)	12.5	(0.492)	20.2	(0.795)	22.4	(0.822)	32.2	(1.268)	35.6	(1.402)
400	400.0	(15.748)	402.4	(15.843)	14.0	(0.551)	22.8	(0.898)	25.2	(0.922)	36.4	(1.433)	40.2	(1.583)
450	450.0	(17.717)	452.7	(17.823)	15.6	(0.614)	25.6	(1.008)	28.3	(1.114)	40.9	(1.610)	45.1	(1.776)
500	500.0	(19.685)	503.0	(19.803)	17.5	(0.689)	28.4	(1.118)	31.4	(1.236)	45.5	(1.791)	50.2	(1.976)
560	560.0	(22.047)	563.4	(22.181)	19.6	(0.772)	31.9	(1.256)	35.2	(1.386)	50.9	(2.004)	56.1	(2.209)
630	630.0	(24.803)	633.8	(24.953)	22.1	(0.870)	35.8	(1.409)	39.5	(1.555)	57.3	(2.256)	63.1	(2.484)

[A]Outside Diameter and maximum out of roundness are in accordance with ISO 4437. Wall thickness is in accordance with ISO 4437 and ISO 11922–1.
[B]Maximum out of roundness applies to straight pipe and pipe prior to coiling for sizes that are packages in coils. Measure out of roundness in accordance with 6.5.1.1 but without rounding equipment applied. See 5.3.1.5 for ovality.

TABLE A1.5 Minimum Wall Thickness and Tolerance, 14 in. and Larger Pipe, in.

Nominal Pipe Size	SDR 32.5	SDR 26	SDR 21	SDR 17	DR 15.5	SDR 13.5	SDR 11	SDR 9	SDR 7.3
14	0.431	0.538	0.667	0.824	0.903	1.037	1.273	1.556	1.918
	+0.052	+0.065	+0.080	+0.099	+0.108	+0.124	+0.153	+0.187	+0.230
16	0.492	0.615	0.762	0.941	1.032	1.185	1.455	1.778	. . .
	+0.059	+0.074	+0.091	+0.113	+0.124	+0.142	+0.175	+0.213	
18	0.554	0.692	0.857	1.059	1.161	1.333	1.636	2.000	. . .
	+0.066	+0.083	+0.103	+0.127	+0.139	+0.160	+0.196	+0.240	
20	0.615	0.769	0.952	1.176	1.290	1.481	1.818	. . .	. . .
	+0.074	+0.092	+0.114	+0.141	+0.155	+0.178	+0.218		
22	0.677	0.846	1.048	1.294	1.419	1.630	2.000	. . .	. . .
	+0.081	+0.102	+0.126	+0.155	+0.170	+0.196	+0.240		
24	0.738	0.923	1.143	1.412	1.548	1.778	2.182	. . .	. . .
	+0.089	+0.111	+1.137	+0.169	+0.186	+0.213	+0.262		

NOTE A1.6—The ring may be tested in its entirety, or may be cut into representative sectors to produce bend-back test specimens.

(*2*) In a well-lit area at 73.4 ± 3.6°F (23 ± 2°C) perform the following procedure within 5 min: (*a*) Bend the specimen inside-out (reverse-bend so that the pipe ID surface is on the outside surface of the bent specimen). (*b*) Using an apparatus such as a vise or other suitable bending equipment, close the legs of the specimen together. When the specimen legs are closed together, the top of the bend-back specimen shall protrude 1 to 1¼ in. (25 to 32 mm) or two wall thicknesses, whichever is greater, above the point of closure (jaws). (*c*) With the unaided (naked) eye, visually examine the protruding reverse-bent pipe ID surface for signs of brittle cracking or crazing.

(*3*) Any indication of brittle cracking or crazing indicates failure.

A1.5.11.2 *Elongation-at-Break Test Method* :

(*1*) Five Test Method D 638 Type IV specimens cut in the longitudinal direction from locations equally spaced around the circumference of the pipe shall be tested in accordance with Test Method D 638 at a cross-head separation speed of 2 in. (50.8 mm) min, and at 73.4 ± 3.6°F (23 ± 2°C). If the specimen thickness must be reduced by machining, the pipe ID surface shall be left unaltered.

NOTE A1.7—If the specimen thickness is reduced, the machined side of the specimen must be smooth and the thickness of the specimen in the gage length must be uniform. Surface cuts or scratches and nonuniform thickness in the specimen gage length can detrimentally affect test results.

(*2*) The percent elongation at break for each test specimen shall exceed 400 %.

A1.5.11.3 *Thermal Stability Test Method* —Specimens of the pipe inside wall surface not more than 0.005 in. (0.13 mm) thick shall demonstrate a minimum induction temperature of 428°F (220°C) when tested in accordance with the Test Method for Thermal Stability in Specification D 3350.

A1.6 Marking

A1.6.1 PE pipe shall be marked with the melt index category in accordance with Table 4 in addition to the marking requirements of 7.1.

A2. SUPPLEMENTAL REQUIREMENTS FOR GAS PRESSURE PIPE AND FITTINGS PRODUCED FROM POLY (VINYL CHLORIDE) (PVC) COMPOUNDS FOR MAINTENANCE OR REPAIR

A2.1 Scope

A2.1.1 This annex covers requirements for PVC pipe for use only to maintain or repair existing PVC gas piping. These requirements are in addition to those in the main body of this specification. All PVC pipe for gas shall be marked per 7.1 (the words "GAS" and "ASTM D 2513" on pipe, etc.) and A2.4.1.7.

A2.1.2 This annex covers requirements for PVC fittings for use to maintain or repair exisiting gas piping. These requirements are in addition to those in the main body of this specification. All PVC fittings for gas shall be marked per 7.2 (the words "ASTM D 2513" on fittings, etc.).

A2.2 Referenced Documents

A2.2.1 *ASTM Standards*: [2]

A2.2.1.1 *Specifications for*:

D 1784 Rigid Poly (Vinyl Chloride) (PVC) Compounds and Chlorinated Poly (Vinyl Chloride) (CPVC) Compounds

D 2241 Poly (Vinyl Chloride) (PVC) Pressure-Related Pipe (SDR Series)

D 2466 Poly (Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule ~~40~~[3] 40

D 2467 Socket Type Poly (Vinyl Chloride) (PVC) Plastic Fittings, Schedule ~~80~~[3] 80

D 2564 Solvent Cements for Poly (Vinyl Chloride) (PVC) Plastic Piping Systems

D 2672 Joints for IPS PVC Pipe Using Solvent Cement

D 2740 Poly (Vinyl Chloride) (PVC) Plastic Tubing

A2.2.1.2 *Test Methods and Practices* :

D 2152 Adequacy of Fusion of Extruded Poly (Vinyl Chloride) (PVC) Pipe and Molded Fittings by Acetone Immersion

D 2412 Determination of External Loading Characteristics of Plastic Pipe by Parallel Plate Loading

D 2444 Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)

D 2855 Making Solvent-Cemented Joints with Poly (Vinyl Chloride) (PVC) Pipe and Fittings

F 402 Safe Handling of Solvent Cements, Primers, and Cleaners Used for Joining Thermoplastic Pipe and Fittings

A2.3 Materials

A2.3.1 PVC pipe and fittings shall be made from the following PVC plastics as defined in Specification D 1784.

Type I, Grade 1, Class 12454B (PVC 11)

Type II, Grade 1, Class 14333D (PVC 21)

A2.4 Requirements

A2.4.1 Requirements for plain end pipe are specified in Specification D 2241. Belled end pipe requirements are specified in Specification D 2672. Fitting requirements are specified in Specification D 2466 for schedule 40 and Specification D 2467 for schedule 80. These fittings are intended for use with corresponding sized outside diameter pipe made from the same compound. The following additional requirements shall also be met.

A2.4.1.1 *Flattening*—There shall be no evidence of splitting, cracking, or breaking by the specimens subjected to this test and performed in accordance with Test Method D 2412. Flatten three specimens of the pipe, 2 in. (50.8 mm) long, between parallel plates in a suitable press until the distance between the plates is 40 % of the outside diameter of the pipe or the walls of pipe touch. The rate of loading shall be uniform and such that the compression is completed within 2 to 5 min. On removal of the load, examine the specimens for evidence of splitting, cracking, or breaking.

A2.4.1.2 *Impact Resistance*—The impact resistance for PVC pipe shall fall within the range specified by the manufacturer's designated Impact Classification Cell (IC). Table A2.1 lists impact classification cell for SDR 17 and 21 pipe. The impact classification rating for PVC pipe shall be determined in accordance with Test Method D 2444 using a flat plate holder and 20-lb tup B for sizes 2 in. and less and 30-lb tup B for all larger sizes. The specimens shall be conditioned in a mixture of ice and water at 32 to 35°F (0 to 2°C) for 1 h (Note A2.1) and tested immediately on removal from this medium.

NOTE A2.1—Other conditioning media such as a refrigerated fluid bath of water and ethylene glycol at 32 to 35°F (0 to 2°C) for 1 h or a refrigerated

TABLE A2.1 Impact Requirements for PVC Pipe at 32 to 35°F (0 to 2°C) for SDR 17 and 21 Pipe

Impact Classification Cell	ft·lbf (J)		
	IC-1	IC-2	IC-3
Nominal Pipe Size, in.			
1	30 to 50 (41 to 68)	>50 to 65 (68 to 88)	>65 (88)
1¼	30 to 51 (41 to 68)	>50 to 65 (68 to 88)	>65 (88)
1½	40 to 60 (54 to 81)	>60 to 75 (81 to 102)	>75 (102)
2	70 to 90 (95 to 122)	>90 to 100 (122 to 136)	>100 (122)
3	120 to 140 (163 to 190)	>140 to 180 (190 to 244)	>180 (244)
4	160 to 200 (217 to 271)	>200 to 240 (271 to 326)	>240 (326)
6	200 to 260 (271 to 353)	>260 to 300 (353 to 407)	>300 (407)

air chamber at 32 to 35°F (0 to 2°C) for 4 h may be used if it can be demonstrated that equivalent results are obtained. However, in cases of disagreement, the ice water mixture shall be used.

A2.4.1.3 *Impact Quality Assurance*— The impact quality assurance is a "GO/NO–GO" test. Five specimens shall be impacted in accordance with Test Method D 2444 using the tup and holder specified in A2.4.1.2 from a height determined by the lower value of the designated Impact Classification (IC) cell. All five specimens shall pass. If one specimen fails, a second set of five specimens shall be tested. None of the second set shall fail. If nine out of the total ten specimens pass, the lot shall be considered to have met the requirements of this test.

NOTE A2.2—This test is intended only for use as a quality control test, not for use as a simulated service test.

A2.4.1.4 *Extrusion Quality*—PVC pipe shall not flake or disintegrate when tested in accordance with the Test Method D 2152.

A2.4.1.5 *Outdoor Storage Stability*— PVC pipe when stored outdoors unprotected for six months from the date of extrusion shall meet all the requirements of this specification. PVC pipe stored outdoors for over six months from date of manufacture, is suitable for use if it meets the requirements of this specification.

A2.4.1.6 *Solvent Cements for PVC Systems*— Solvent cements for PVC pipe and fittings shall meet the requirements of Specification D 2564.

A2.4.1.7 *Marking*—Impact Classification Cell, as determined by the manufacturer, shall be printed on the pipe in addition to the marking requirements of 7.1.

A2.4.1.8 *Minimum Hydrostatic Burst Strength/Apparent Tensile Strength*—The minimum burst pressure for PVC pipe shall be as given in Table A2.2 or as calculated (using the actural measured minimum wall, the actual measured average outside diameter, and the applicable fiber stress shown in Table A2.3) when determined in accordance with Test Method D 1599. For sizes above 4-in. nominal diameter, the testing laboratory shall be allowed to replace the quick burst (Test Method D 1599) by the apparent ring tensile strength test (Test Method D 2290). The minimum fiber stress shall be as given in Table A2.3.

A2.4.1.9 *Sustained Pressure 73°F (23°C)*—The pipe or system shall not fail in less than 1000 h when tested in accordance with Test Method D 1598. The stress shall be as given in Table A2.3.

A2.5 Safety Requirements

A2.5.1 Safety requirements for handling solvent cements shall be observed. Consult Practice F 402 and the solvent cement manufacturer for appropriate precautions.

TABLE A2.2 Minimum Burst Pressure Test Requirements for PVC Pipe at 73°F (23°C)

Standard Demension Ratio	Minimum Burst Pressure, psi (MPa)	
	PVC 1120	PVC 2110 PVC 2116
11	1250 (8.6)	1000 (6.9)
13.5	1000 (6.9)	800 (5.5)
17	800 (5.5)	630 (4.3)
21	630 (4.3)	500 (3.4)

TABLE A2.3 Minimum Fiber Stress, psi (MPa)

	Minimum Hydrostatic Burst Strength and Apparent Tensile Tests	Sustained Pressure Test
PVC 1120	6400 (44.1)	4200 (29.0)
PVC 1220	6400 (44.1)	4200 (29.0)
PVC 2110	5000 (34.5)	2300 (15.9)
PVC 2116	5000 (34.5)	3650 (23.2)

A3. IN-PLANT QUALITY CONTROL PROGRAM FOR PLASTIC PIPE AND FITTINGS UP TO AND INCLUDING 12 IN. NOMINAL DIAMETER

A3.1 Quality Control

A3.1.1 The following in-plant quality control program shall be used to assure compliance with this specification. The pipe and fittings producers shall maintain records on all aspects of this program and supply these to the purchaser, if requested.

A3.1.2 *In-Plant Quality Control Test Methods*—Test methods other than those specified in Section 6 are used as long as they provide equivalent results. In case of disagreement, those test methods in the applicable ASTM standard shall be used.

A3.2 Pipe Tests

A3.2.1 *Material and Extrusion Process Qualification*—Sustained pressure tests shall be made on one pipe size in the range of 2 in., or less, and on one pipe size in the range of 2½ in., or greater. This test shall also be made on pipe from each particular commercial plastic resin initially, and at least twice a year thereafter for material and extrusion process qualification and not as a quality control on the product. This test shall be made in accordance with 6.6.1, 6.6.1.1 and 6.6.3 using either of the test conditions in Table A3.1 for PE, and in accordance with 6.6 for other materials.

A3.2.2 *Product Quality Control* (Note A3.1) The tests in Table A3.2 shall be made per size per extrusion die at the denoted frequencies and the test results recorded and filed for inspection on request.

NOTE A3.1—When the pipe fails to meet this specification in any test, additional tests shall be made on the pipe produced back to the previous acceptable result to select the pipe produced in the interim that does pass the requirement. Pipe that does not meet the requirement shall be rejected.

NOTE A3.2—For pipe sizes above 4-in. nominal diameter, the quick burst test (Test Method D 1599) may be replaced by the Apparent Ring Tensile Strength Test (Test Method D 2290) if agreed to between the purchaser and the manufacturer.

A3.2.3 *Burst Pressure Multilevel Plan* (see Fig. A3.1)— This multilevel plan is based on MIL-STD-1235 (ORD), and is used only when the same product is extruded continuously under the same operating conditions and production is at a steady rate. Before this reduced sampling plan is considered, steady production conditions must be carefully chosen to ensure a continuous and consistent high quality output. Any interruption (shutdown) or change in resin lot number, percentage rework, or production conditions outside normal operating variations shall cause sampling to revert to Level 1. A sampling level change is considered only when approved by a production supervisor or authorized quality control personnel.

Level 1 Test one specimen every 8 h. If 16 consecutive specimens have met requirements, proceed to Level 2.

Level 2 Collect one specimen every 8 h. After 72 h (3 days) or portion thereof, test two randomly selected specimens. If both pass, discard the remaining 7 specimens. If any specimen fails to meet requirements, revert to Level 1 (see also Note A2.1). Product for which a specimen has been collected shall not be shipped until after the 72-h time period and randomly selected samples have been tested. Continue to test 2 out of 9 specimens for 16 three-day periods (48 days of production), then proceed to Level 3.

Level 3 Collect one specimen every 8 h. After 21 days or portion thereof, test three randomly selected specimens. If all three pass, discard the remaining specimens. If any specimen fails to meet requirements, revert to Level 1 (see also Note A3.1). Product for which a specimen has been collected shall not be shipped until after the 21-day time period. Continue testing at Level 3 until production conditions necessitate reverting to Level 1.

TABLE A3.1 PE Material and Extrusion Process Qualification Test Conditions[A]

Temperature	Stress	Time Requirement
176 ± 3.6°F (80 ± 2°C)	580 ± 10 psi (4.0 ± 0.07 MPa)	1000 h
176 ± 3.6°F (80 ± 2°C)	670 ± 10 psi (4.6 ± 0.07 MPa)	170 h

[A] Methane should not be substituted for water in this 176°F (80°C) test.

TABLE A3.2 Product Quality Control Tests

Property	Frequency
Diameter	once every hour or every coil, whichever is less frequent
Wall thickness	once every hour or every coil, whichever is less frequent
Ring tensile or burst pressure	Once every 8 h or once every coil, whichever is less frequent, or multilevel plan described in A3.2.3
Flattening (PVC only)	once every 8 h
Extrusion quality (PVC only)	once every 2 h
Impact resistance (PVC only)	once every hour

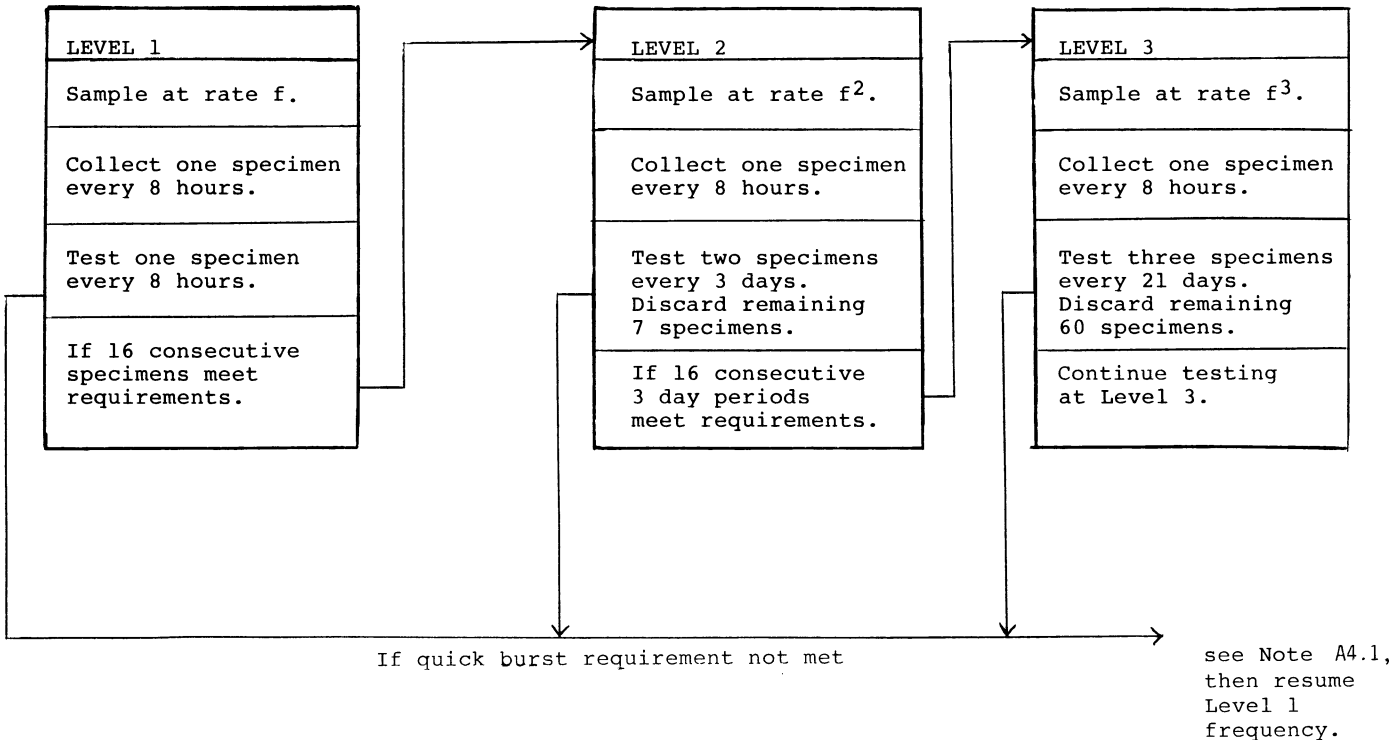

FIG. A3.1 Quick Burst Multilevel Sampling Plan

A3.3 Fittings Tests[9]

A3.3.1 The fittings tests listed in the following sub-paragraphs shall be conducted at the frequencies indicated.

NOTE A3.3—When any fitting fails to meet the requirements of this specification, or the applicable referenced fitting specification, additional tests should be made on fittings produced back to previous acceptable result to select the fittings produced in the interim that do meet the requirements. Fittings that do not meet the requirements shall be rejected.

A3.3.2 *Dimensions*:

A3.3.2.1 *Socket Fittings:*

(a) *Socket Entrance, Bottom and Minimum Internal Diameters*—Once an hour or one out of ten fittings, whichever is less frequent.

(b) *Wall Thickness*—At the beginning of each production setup for each cavity.

A3.3.2.2 *Butt Fusion Fittings:*

(a) *Outside Diameter and Wall Thickness* —Once an hour or one out of ten fittings, whichever is less frequent.

A3.3.3 *Other Tests:*

A3.3.3.1 *PVC Fittings*—The burst pressure shall be measured on one fitting per 8-h production.

A3.3.3.2 *PE and PB Fittings*—At the start of each production run, whenever production conditions have changed, or when the resin lot is changed, but not less frequently than once per 500 fittings thereafter, the following tests shall be made:

[9] The boldface numbers in parentheses refer to the list of references at the end of this standard.

[9] Supporting data are available from ASTM Headquarters. Request RR: F17-1018.

(a) The knit line strength for at least one fitting from each cavity shall be demonstrated by one of the following tests:

[1] Crushing a fitting, or a portion of a fitting, in a manner that applies load in the direction normal to the knit line. See Note A3.4.

[2] Apparent tensile strength tests of a ring cut from a fitting, with the load oriented normal to the knit line. See Note A3.5.

[3] Burst testing of the fitting. See Note A3.5.

(b) The integrity of at least one part from each mold cavity shall be verified, using a method selected by the manufacturer as appropriate for this specific product and process.

NOTE A3.4—Separation in the knit constitutes a failure.

NOTE A3.5—In tests 2 and 3 the strength requirements shown in the annexes must be met.

A4. IN-PLANT QUALITY CONTROL PROGRAM FOR 14-IN. AND LARGER DIAMETER POLYETHYLENE PIPE

A4.1 Visual inspection of every length of pipe for workmanship defects shall be carried out at the manufacturer's plant. Measurements of outside diameter and wall thickness shall be made for each hour's production or each length of pipe, whichever is less frequent.

A4.2 Lengths of pipe that are shorter than standard shipping lengths are butt-fused to produce standard lengths. Such build-up lengths must otherwise meet all of the product requirements of this specification.

A4.3 Manufacturers of pipe shall conduct such other quality control tests as are appropriate to their manufacturing operations that will provide assurance that the product requirements of A1.5 will be met in place of the actual performance of the specified tests.

NOTE A4.1—The pressure tests required under product requirements are tests for performance. These tests are not adaptable to in-plant quality control. Quality control tests have not been standardized because the requirements for such tests vary substantially from one manufacturing plant to another.

A5. SUPPLEMENTAL REQUIREMENTS FOR GAS PRESSURE PIPE AND FITTINGS PRODUCED FROM POLYAMIDE MATERIAL

A5.1 Scope

A5.1.1 This annex covers requirements for PA pipe and heat fusion fittings. These requirements are in addition to those in the main body of this specification.

A5.2 Referenced Documents

A5.2.1 *ASTM Standards*: [2]

D 4066 Specification for Nylon Injection and Extrusion Materials (PA)

F 1563 Specification for Tools to Squeeze-Off Polyethylene (PE) Gas Pipe or Tubing

A5.3 Materials

A5.3.1 *Classification*—Polyamide materials suitable for use in the manufacturing of pipe and fittings under this specification shall be classified in accordance with Specification D 4066, as shown in Table A5.1.

A5.3.2 *Short- and Long-Term Properties*— Polyamide pipe and fittings shall be made from a PA material which also satisfies the combinations of short- and long-term property requirements shown in Table A5.2.

A5.4 Requirements for Pipe and Fittings

A5.4.1 *Conditioning*—For those tests where conditioning is required, or unless otherwise specified, condition the specimens prior to testing for a minimum of 1 h in water or 4 h in air at 73.4 ± 3.6°F (23 ± 2°C) or in accordance with 6.3. The conditioning requirements of 6.3 shall be used in all cases of disagreement.

A5.4.2 *Minimum Hydrostatic Burst Pressure/Apparent Tensile Strength (Quick Burst)*—The pipe or system shall fail in a ductile manner when tested in accordance with Test Method D 1599 at a stress greater than 3900 psi (27 MPa). For pipe sizes above 4-in. nominal diameter, the testing laboratory shall be allowed to replace the quick burst test (Test Method D 1599) by the apparent ring tensile strength test (Test method D 2290). The minimum apparent tensile strength at yield when determined in accordance with 6.8 shall be 3900 psi (27 MPa).

A5.4.3 *Sustained Pressure at 73°F (23°C)*—The pipe or system shall not fail in less than 1000 h when tested in accordance with Test Method D 1598. The stress shall be 2800 psi (19 MPa).

A5.4.4 *Squeeze Off*—This requirement is limited to pipe sizes, wall thicknesses, squeeze procedures, and conditions deemed suitable for squeeze-off in service by the pipe manufacturer. There shall be no leakage or visual evidence of splitting, cracking,

TABLE A5.1 Specification D 4066 Classification

Classification	Designation
PA	Polyamide
3 (group)	11 nylon
2 (class)	Heat stabilized
3 (grade)	
Relative viscosity, min	1.83
Melt point, °C	185–195
Specific gravity	1.03–1.06
Tensile strength, min, MPa	48
Elongation (ultimate), min, %	200
Flexural modulus, min, MPa	900
Izod impact resistance, min, J/M	55
Deflection temperature, min at 1.82 MPa	40
Moisture “as received”, %, max	0.08

TABLE A5.2 Short and Long Term Property Requirements

PA Material Designation Code	Short-Term in Accordance with D 4066	Long-Term in Accordance with D 2837
PA32312	PA323	HDB of 2500 psi for 73°F (23°C)

breaking, or reduction in 1000-h sustained pressure category when pipe is tested as follows:

A5.4.4.1 Prepare six randomly selected pipe specimens in accordance with Test Method D 1598, except they shall be unfilled.

A5.4.4.2 The squeeze-off shall be effected at the midpoint of the test specimen, 90° to the point of the measured minimum wall thickness. Close the squeeze bars to the gap stop in Specification F 1563 and hold in constraint for 4 h. Remove squeeze bars and reround pipe by closing squeeze bars at a point 90° for the squeeze area.

A5.4.4.3 Immediately upon removal of the squeeze-off tool, fill the specimens with ambient temperature water, that is 67 ± 10°F (19.4 ± 5.0°C), condition, and test in accordance with 6.6.

A5.4.5 *Outdoor Storage Stability*— PA pipe stored outdoors and unprotected for at least two years from date of manufacture shall meet all the requirements of this specification. PA pipe stored outdoors for over two years from date of manufacture is suitable for use if it meets the requirements of this specification.

A5.4.6 *Chemical Resistance*—The weight, yield strength, and inherent viscosity requirements for polyamide pipe when measured in accordance with 6.9 are in Table A5.3.

A5.5 Marking

A5.5.1 PA pipe shall be marked with the elevated temperature code letters EF CG in accordance with Table 4 in addition to the marking requirements of 7.1.

E = maximum temperature of 180°F (82°C),

TABLE A5.3 Chemical Resistance

Chemical	Weight Change, max %	Yield Strength Change, max %	Inherent Viscosity, %
Mineral oil	+0.5	−12	±3
Tertiary-butyl mercaptan (5 %)	+0.5	−12	±3
Methanol	+5	−35	±3
Ethylene glycol	+0.5	−12	±3
Toluene (5 %)	+7	−40	±3

F = 1250 psi HDB at 180°F (82°C),
C = temperature of 140°F (60°C), and
G = 1600 psi HDB at 140°F (60°C).

A6. SUPPLEMENTAL REQUIREMENTS FOR GAS PRESSURE PIPE PRODUCED FROM MAGNETIC-DETECTABLE POLYETHYLENE MATERIAL (MDPEMAG/HDPEMAG) WITH UP TO 24 % CONCENTRATION (WEIGHT PERCENT) OF STRONTIUM FERRITE (SrFe)

A6.1 Scope

A6.1.1 This annex covers requirements for magnetic-detectable PE pipe and tubing with up to 24 % concentration by weight of Strontium Ferrite (SrFe). These requirements are in addition to those in the main body of this specification.

NOTE A6.1—The use of the term Magnetic-detectable Polyethylene (Magnetic-detectable PE) throughout the body of this annex refers to only conventional grades of PE (medium and high density) blended with up to 24 % (by weight) concentration of Strontium Ferrite (SrFe) only. While other fillers can be added, this annex is restricted to SrFe only on the basis of the comprehensive testing and evaluation on the chemical, physical, and mechanical properties of the magnetic-detectable PE. Magnetic-detectable PE is a patented technology exclusively owned by Gas Technology Institute (formerly Gas Research Institute).

A6.2 Referenced Documents

A6.2.1 *ASTM Standards*: [2]
A6.2.1.1 *Test Methods for*:
D 1238 Melt Flow Rate of Thermoplastics by Extrusion Plastometers
D 1598 Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
D 1599 Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings
D 2290 Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe by Split Disk Method
D 2837 Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials
F 1473 Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipes and Resins
A6.2.1.2 *Specification for*:
D 3350 Polyethylene Plastic Pipe and Fitting Materials
F 1563 Tools to Squeeze Off Polyethylene (PE) Gas Pipe or Tubing
A6.2.2 *PPI Documents*
A6.2.2.1 PPI TR4 Hydrostatic Design Bases and Maximum Recommended Hydrostatic Design Stresses for Thermoplastic Piping Materials

A6.3 Materials

A6.3.1 *Cell Classification and Strontium Ferrite Blending*—Polyethylene materials for blending with strontium ferrite shall be PE2406 (MDPE) material meeting a cell classification of 234363C or 234263E per specification D 3350, or PE3408 (HDPE) material meeting a cell classification of 345464C or 345464E per specification D 3350. These materials shall be blended with up to a maximum of 24 % concentration level by weight of strontium ferrite (SrFe)

A6.3.1.1 *MDPEMAG*—PE2406 material that is blended with a maximum of 24 % concentration level by weight of strontium ferrite, shall be listed by PPI TR4 with a minimum hydrostatic design basis (HDB) ratings of 1250 psi (8.62 MPa) at 73°F (23°C) and 800 psi (5.52MPa) at 140°F (60°C)

A6.3.1.2 *HDPEMAG*—PE3408 material that is blended with a maximum of 24 % concentration level by weight of strontium ferrite, shall be listed by PPI TR4 with a minimum hydrostatic design basis (HDB) ratings of 1600 psi (11.03 MPa) at 73°F (23°C) and 800 psi (5.52MPa) at 140°F (60°C)

A6.3.1.3 *Strontium Ferrite (SrFe)*—Strontium Ferrite materials must conform to typical powder characteristics shown in Table A6.1.

A6.3.2 *Short and Long Term Properties* —Polyethylene pipe and tubing shall be made from magnetic-detectable PE materials which also satisfy the combinations of short- and long-term property requirements shown in Table A5.2.

TABLE A6.1 Typical Powder Characteristics of Strontium Ferrite

Characteristic	Units	Value
Chemical Composition		$SrFe_{12}O_{19}$
Theoretical Density	g/cm^3	5.09
Bulk Density	kg/m^3	2243
+325 Mesh	wt. %	5
Average Particle Size (FSS-Fisher sub-sieve Sizer, 5.15 gram sample)	microns	3.5

A6.3.3 *Hydrostatic Design Basis (HDB) Substantiation*—The HDB for magnetic-detectable PE materials at 73°F (23°C) shall be substantiated by showing that the extrapolation of the stress regression curve is linear to the 438 000-h intercept (long term hydrostatic strength at 50 years in accordance with Test Method D 2837). This will be done in accordance with Test Method D 2837 using one of the two following procedures:

A6.3.3.1 Use the twelve data points from Conditions I and II obtained in 5.6.1 (Procedure I) of Test Method D 2837 along with the 438 000-h intercept to solve for the three-coefficient rate process extrapolation equation. Then using this new model, calculate the mean estimated failure time for Condition III. When the log average time for six specimens tested at Condition III has reached this time, linear extrapolation of 73°F (23°C) stress regression curve to 438 000-h is substantiated.

A6.3.3.2 When 5.6.2 (Procedure II) of the Test Method D 2837 is used to validate the 73°F (23°C) HDB linear extrapolation of the stress regression curve to 438 000-h is substantiated when the log average failure time of the test specimens at 176°F (80°C) surpasses 6000 hours.

NOTE A6.2—For less than 2 in. IPS (60.3 mm) pipe and tubing that has been magnetized to induce a characteristic sinusoidal signature, a maximum of 24 % concentration level by weight of strontium ferrite (SrFe) in polyethylene has been identified as effectively detectable at typical burial depths. For 2 in. IPS (60.3 mm) and larger pipe and tubing that has been magnetized to induce a characteristic sinusoidal signature, a 17 % concentration level by weight of strontium ferrite (SrFe) in polyethylene has been identified as effectively detectable at burial depths of 3 to 5 feet (0.9 to 1.5 m). Supporting information in a Research Report. RR-F17-1018, has been filed with ASTM headquarters.

NOTE A6.3—For more information on the AILM Magnetizer Unit contact Gas Technology Institute (GTI) 1700 S. Prospect Rd., Des Plaines, IL 60018

NOTE A6.4—Melt index ranges for magnetic detectable PE with up to 24 % concentration by weight of strontium ferrite are summarized in Table 4.

NOTE A6.5—The long term hydrostatic strength at 50 years in accordance with Test Method D 2837 is not to be used for any pressure rating calculations. The MAOP is still calculated using the HDB obtained from Test Method D 2837 long term hydrostatic strength at 100 000 hours.

A6.3.3.3 *Slow Crack Growth Resistance* —Test Method is F 1473 on compression molded plaques. Stress is 2.4 MPa based on the unnotched area. Temperature is 80°C. Notch depth in accordance with Table 1 in Test Method F 1473. The minimum of the average of the two tests shall be 100 h. Do at least four tests in case of dispute.

A6.3.3.4 *Additive Classes*—Magnetic-detectable materials shall be Code Letter C or E as defined in Specification D 3350.

A6.4 Fittings

A6.4.1 Fittings intended for use with corresponding sized outside diameter magnetic-detectable pipe and tubing shall meet the requirements of the main body of this specification, Annex A1, and Annex A3.

A6.5 Requirements

A6.5.1 *Magnetization and Magnetic Detectability*—Pipe and tubing shall be magnetized during the extrusion process by passing the pipe through a "magnetizer" containing a rotating permanent magnet core that magnetizes the strontium ferrite particles with a characteristic sinusoidal pattern.

A6.5.1.1 *Magnetizer*— For less than 2 in. IPS (60.3 mm) pipe and tubing, AILM 2.375 magnetizer unit must be used. For pipe and tubing larger than 2 in. IPS (60.3 mm) and less than 4 in. IPS (114.3 mm), AILM 4.0 magnetizer unit must be used. For 2 in. IPS (60.3 mm), either AILM 2.375 or AILM 4.0 can be used.

A6.5.1.2 *Magnetizer Rotation Speeds* —The rotation speed of the magnet core contained within the" magnetizer" unit shall be calculated for each pipe size as a function of the line speed using the following equation:

$$\omega = V/(12\lambda) \quad \text{(A6.1)}$$

where:

ω = rotation speed of the magnet core, r/min
V = line speed, in./min.
λ = one single period as measure from peak to peak on a sin function graph. For gas distribution application, λ = 10 ft.

A6.5.2 *Conditioning*— For those tests where conditioning is required or unless otherwise specified, condition the specimens prior to testing for a minimum of 1 h in water or 4 h in air at 73.4 ± 3.6°F (23 ± 2°C) or in accordance with 6.3. The conditioning requirements of 6.3 shall be used in all cases of disagreement.

A6.5.3 *Minimum Hydrostatic Burst Pressure/Apparent Tensile Strength (Quick Burst)*—The pipe or system shall fail in a ductile manner when tested in accordance with Test Method D 1599. For pipe size above 4-in. nominal diameter, the quick burst test (Test Method D 1599) may be replaced by the apparent ring tensile strength test (Test Method D 2290). The minimum apparent tensile strength at yield when determined in accordance with 6.8 shall be 2520 psi (17.4 MPa).

A6.5.4 *Sustained Pressure 73°F (23°C)*—The pipe or system shall not fail in less than 1000 h when tested in accordance with Test Method D 1598. For MDPEMAG material, the stress shall be 1320 psi, for HDPEMAG materials, the stress shall be 1600 psi.

A6.5.5 *Melt Index*— Melt index is the flow rate of Magnetic-detectable PE material when measured in accordance with Test Method D 1238, condition 190/2.16 (formerly Condition E). Materials that record zero flow under condition 190/2.16 shall be measured in accordance with condition 190/21.6 (formerly condition F). The melt index of pipe shall meet the designated category in Table 4. The sample shall be representative of the cross section of the pipe and diced to an appropriate size by a method not producing heat.

A6.5.6 *Squeeze-off*— This requirement is limited to pipe sizes, wall thicknesses, squeeze procedures and conditions deemed suitable for squeeze-off in service by the pipe manufacturer. There shall be no leakage or visual evidence of splitting, cracking, breading or reduction in 1000-h sustained pressure category when pipe is tested as follows:

A6.5.6.1 Prepare six randomly selected pipe specimens in accordance with Test method D 1598.

A6.5.6.2 The squeeze-off shall be effected at the midpoint of test specimen, 90° to the point of the measured minimum wall thickness. Close the squeeze bars to the gap stop recommended in Specification F 1563 and hold in constraint for 4 h. Remove squeeze bar and reround pipe by closing squeeze bars at a point 90° from the squeeze area.

A6.5.6.3 Immediately upon removal of the squeeze-off tool, fill the specimens with ambient temperature water, that is, 67 ± 10°F (19.4 ± 5.6°C), condition, and test in accordance with 6.6.

A6.5.7 *Thermal Stability*—The Magnetic-detectable PE material shall contain sufficient antioxidant so that the minimum induction temperature shall be 428°F (220°C) when tested in accordance with Specification D 3350. The sample shall be representative of the cross section of the pipe.

A6.5.8 *Outdoor Storage Stability* —Magnetic-detectable PE pipe stored outdoors and unprotected for at least two years from date of manufacture shall meet all the requirements of this specification. Magnetic-detectable PE pipe stored outdoors for over two years from date of manufacture may be used if it meets the requirements of this specification.

A6.5.9 *Dimensions and Tolerances* —The outside diameter shall meet the requirements in Tables 1 and 2 in the main body for sizes up to 12 in. The minimum wall thickness shall meet the requirements in Table 2 and Table 3 in the main body for sizes through 12 in., or in Table A1.5 for larger sizes. When sizes other than those listed in these tables are used, the tolerances on outside diameter shall be the average outside diameter ±0.45 %, or minimum outside diameter −0, +0.9 %, and the tolerance on minimum wall thickness shall be −0, +12 %.

A6.5.10 *Short Term Pressurization for Sizes Above 12 in.*—Magnetic-detectable PE pipe shall not fail when tested in accordance with Test Method D 1599 with the hoop stress of 2500 psi for MDPEMAG materials or 2900 psi for HDPEMAG materials. Hoop stress calculation shall be based on the DR. (**Warning—**Pressurization of pipe specimens above 12 in. nominal diameter being tested in accordance with A6.5.9 should not commence until it is certain that all entrapped air has been bled from water-filled specimens.)

NOTE A6.6—The requirements in A6.5.9 are for laboratory proof testing only and should not be interpreted as applicable to on-site testing for acceptance of installed systems larger than 12 in. See appropriate installation standards or manufacturer's recommendations for field test procedures.

A6.5.11 *HDBC Validation for Magnetic-detectable PE Pipe*—The 73°F (23°C) Hydrostatic Design Basis Category (HDBC) of Magnetic-detectable PE pipe shall be validated by the pipe producer using the PE validation procedure as outlined in Test Method D 2837. For MDPEMAG material, the HDBC of 1250 psi shall be validated; for HDPEMAG material, the HDBC of 1600 psi shall be validated.

A6.6 Marking

A6.6.1 Magnetic-detectable PE pipe and tubing shall be marked with the melt index category in accordance with Table 4 in addition to the marking requirements of 7.1.

A6.7 Quality Control

A6.7.1 In-plant quality control program requirements contained within Annex A3 shall be used to ensure compliance with this specification. The pipe producers shall maintain records on all aspects of this program and supply these to the purchaser, if requested.

A7. SUPPLEMENTAL REQUIREMENTS FOR GAS PRESSURE PIPE PRODUCED FROM CROSSLINKED POLYETHYLENE (PEX) MATERIAL

A7.1 Scope

A7.1.1 This annex covers requirements for PEX pipe. These requirements are in addition to those in the main body of this specification.

A7.2 Referenced Documents

A7.2.1 *ASTM Standards*: [2]

A7.2.1.1 *Test Methods for*:

D 792 Density and Specific Gravity (Relative Density) of Plastics by Displacement

D 1505 Density of Plastics by Density-Gradient Technique

D 2765 Determination of Gel Content and Swell Ratio of Crosslinked Ethylene Plastics

D 4883 Density of Polyethylene by Ultrasound Technique

A7.3 Materials

A7.3.1 *General*—PEX pipe are primarily defined by means of three criteria, namely, *(1)* nominal density, *(2)* degree of crosslinking, and *(3)* long-term strength tests. There is a strong correlation between nominal density and results of short-term strength tests.

A7.3.2 *Basic Materials*— PEX pipe shall be made from polyethylene compounds which have been crosslinked by peroxides, Azo compounds, or silane compounds in extrusion, or by electron beam after extrusion, or by other means such that the pipe meets the performance requirements of this Annex. The materials, procedure for mixing, and the process for crosslinking shall result in a product with minimum recommended long term hydrostatic design basis (HDB) equal to or greater than 1250 psi at 73.4°F (23°C) and 800 psi at 180°F (82.2°C) when determined in accordance with PPI TR-3 and Test Method D 2837.

A7.3.3 *Density*—The PEX pipe material shall have a minimum density of 0.926 g/cc when determined in accordance with Test Method D 1505, D 792, or D 4883.

A7.3.4 *Rework Material*— PEX pipes shall not be used in the manufacture of pipes to this Annex.

A7.3.5 *Pipe Material Designation* —The pipe meeting the requirements of this Annex shall be designated PEX.

A7.4 Requirements for Pipe

A7.4.1 *Conditioning*— For those tests where conditioning is required or unless otherwise specified, condition the specimens prior to testing for a minimum of 1 h in water or 4 h in air at 73.4 ± 3.6°F (23 ± 2°C) or in accordance with 6.3. The conditioning requirements of 6.3 shall be used in all cases of disagreement.

A7.4.2 *Minimum Hydrostatic Burst Pressure/Apparent Tensile Strength (Quick Burst)*—The pipe shall fail in a ductile manner when tested in accordance with Test Method D 1599. For pipe sizes above 4-in. nominal diameter, the testing lab shall be allowed to replace the quick burst test (Test Method D 1599) by the apparent ring tensile strength test (Test Method D 2290). The minimum apparent tensile strength at yield when determined in accordance with 6.8 shall be 2520 psi (17.4 MPa).

A7.4.3 *Sustained Pressure 73°F (23°C)*—The pipe shall not fail in less than 1000 h when tested in accordance with Test Method D 1598. For PEX 0006 material, the stress shall be 1320 psi (9.1 MPa), for PEX 0008 material, the stress shall be 1600 psi (11.03 MPa).

A7.4.4 *Elevated Temperature 203°F (95°C)*—The pipe shall not fail in less than 165 h when tested in accordance with Test Method D 1598. For PEX 0006 and 0008 materials, the stress shall be 550 psi (3.8 MPa).

A7.4.5 *Degree of Crosslinking*—The degree of crosslinking for PEX pipe shall be within the range from 65 to 89 % inclusive. Depending on the process used, the following minimum percentage crosslinking values shall be achieved: 70 % by peroxides, 65 % by Azo compounds, 65 % by electron beam, or 65 % by silane compound. The degree of crosslinking on a pipe sample is obtained as follows:

A7.4.5.1 Place a pipe sample in a lathe with automatic feeding. Shave a strip that consists of the full wall thickness. The strip thickness shall be approximately 0.004 in. (0.1 mm) which is obtained by setting the lathe feeding accordingly.

A7.4.5.2 Test the specimens in accordance with Test Method D 2765, Method B, with the only deviation: test specimen preparation. For the purpose of this specification, degree of crosslinking (V) is defined as 100 % minus extract percent equals V.

NOTE A7.1—Test Method D 2765, Method A may be used in lieu of Method B. Method A gives more accurate and reproducible values but require a special grinder for sample preparation.

A7.4.6 *Squeeze-Off*— This requirement is limited to pipe sizes, wall thicknesses, squeeze procedures, and conditions deemed suitable for squeeze-off in service by the pipe manufacturer. There shall be no leakage or visual evidence of splitting, cracking, breaking or reduction in 1000-h sustained pressure category when pipe is tested as follows:

A7.4.6.1 Prepare six randomly selected pipe specimens in accordance with Test Method D 1598 except they shall be unfilled.

A7.4.6.2 The squeeze-off shall be effected at the mid-point of the test specimen, 90° to the point of the measured minimum wall thickness. Close the squeeze bars to the gap stop in Specification F 1563 and hold in constraint for 4 h. Remove squeeze bar and reround pipe by closing squeeze bars at a point 90° from the squeeze area.

A7.4.6.3 Immediately upon removal of the squeeze-off tool, fill the specimens with ambient temperature water, that is 67 ± 10°F (19.4 ± 5.6°C), condition, and test in accordance with 6.6.

A7.4.7 *Thermal Stability*—Specimens of the pipe inside wall surface not more than 0.005 in. (0.13 mm) thick shall demonstrate a minimum induction temperature of 428°F (220°C) when tested in accordance with the Test Method for Thermal Stability in Specification D 3350.

A7.4.8 *Outdoor Storage Stability* —PEX pipe stored outdoors and unprotected for at least two years from date of manufacture shall meet all the requirements of this specification. PE pipe stored outdoors for over two years from date of manufacture is suitable for use if it meets the requirements of this specification.

A7.4.9 *Apparent Tensile Strength at Yield*—When tested in accordance to 6.8, the PEX pipe shall demonstrate a minimum of 2600 psi for PEX 0006 materials and 3000 psi for PEX 0008 materials.

A7.4.10 *Slow Crack Growth Resistance* —Test Method is F 1473 on compression molded plaques or PEX pipe sample. Stress is 2.4 MPa based on unnotched area. Temperature is 80°C. Notch depth in accordance with Table 1 in Test Method F 1473. The minimum of the average of the two tests shall be 100 h. Do at least four tests in case of a dispute.

A7.5 Marking

A7.5.1 PEX pipe shall be marked with the marking requirements of 7.1.

APPENDIXES

(Nonmandatory Information)

X1. NEW MATERIALS

X1.1 It is the intent of ASTM Committee F17 on Plastic Piping Systems to consider for inclusion other kinds, types, and grades of thermoplastics in this specification, when evidence is presented to show that they are suitable for underground distribution of natural gas. Minimum requirements, in addition to all the pertinent parts of this specification are: (1) an ASTM material specification, (2) and ASTM product specification, (3) the material's long-term hydrostatic strength, determined in accordance with an appropriate test method such as Test Method D 2837, and (4) at least 3 years of service-related evidence to demonstrate that the material has performed satisfactorily as underground gas pressure piping.

X1.2 Each candidate material is considered individually with respect to its own properties, the intended application, and other pertinent usage experience. Experience with a related approved material may be applicable to a new material provided the germane correlations can be demonstrated.

X1.3 An example of appropriate evidence to meet service related requirements, but not necessarily the only way, would be a minimum of 3 years evaluation of representative piping systems in gas service under representative conditions without significant change in physical or mechanical properties. Such systems should aggregate at least 1000 ft (305 m) of piping to provide an ample basis for statistical evaluation. Piping systems should contain representative pipe sizes and companion pipe fittings such as elbows, tees, couplings, and caps. Recommendations for making individual service connections on both pressured and unpressured systems is also desirable information. If special backfill materials or techniques are necessary for satisfactory performance, they should be so stated and described; otherwise generally accepted industry practices are assumed to be adequate. Publications of the American Gas Association and the Plastic Pipe Institute contain information which may be useful in assessing the suitability or relevancy of candidate materials.

X2. DESIGN CONSIDERATIONS

X2.1 General

X2.1.1 The design of a plastic piping system for natural gas service must include consideration of the combined effects of time, internal and external stress, and environment as an overall basis for selecting a specific kind and size of plastic pipe. The design stress for plastic pipe used for distribution of natural gas and petroleum fuels is regulated by the U.S. Department of Transportation as published in Part 192 Title 49 of the Code of Federal Regulations. The American Gas Association Plastic Materials Committee, the Fuel Gas Division of PPI, and members of ASTM Committee F17 are cooperating with the ASME Gas Piping Technology Committee to provide assistance in selecting safe design stress levels for the various kinds of plastic pipe.

X2.2 Design Equations

X2.2.1 *Relationship Between Pipe Stress and Pressure*—The following expression is used to relate stress, pressure, pipe size, and wall thickness:

$$P = 2S/(DR - 1) \text{ or } 2S/[(D_o/t) - 1] \quad \text{(X2.1)}$$

where:

S = stress in the circumferential or hoop direction, psi (MPa),
P = internal pressure, psig (MPa),
DR = dimension ratio,
D_o = average outside diameter, in. (mm), and
t = minimum wall thickness, in. (mm).

X2.2.2 The following expression can be used to determine the burst pressure or sustained pressures needed in testing:

$$P_b = 2S_y/(DR - 1) \quad \text{(X2.2)}$$

where:

P_b = burst pressure, psig (MPa),

S_y = yield stress, psi (MPa), and
DR = dimension ratio.

$$P_s = 2S_f/(DR - 1) \quad \text{(X2.3)}$$

where:
P_s = sustained pressure, psig (MPa),
S_f = fiber stress psi (MPa), and
DR = dimension ratio.

X2.2.3 *Relation between Hydrostatic Design Basis (HDB) and Hydrostatic Design Stress (HDS)*—The *HDS* is determined by multiplying the *HDB* by a design factor, *f*. The design factor, *f*, has a value less than 1.0.

$$HDS = (HDB)(f) \quad \text{(X2.4)}$$

NOTE X2.1—The actual choice of design factor for a given installation must be reviewed by the design engineer taking into account federal, state, and local code requirements. For example, the design factor for gas pipelines under the jurisdiction of the Department of Transportation is 0.32.

X2.3 Design Stress and Internal Pressure for Natural Gas

X2.3.1 The design stresses for natural gas pipe are based on the hydrostatic design basis at 73°F (23°C) obtained in accordance with Test Method D 2837. The test medium should be natural gas or simulated natural gas except that water may be used where previous tests have shown that for the particular type of plastic, water and natural gas give essentially the same test results. The hydrostatic design basis of the plastics presently included in the applicable ASTM specifications are as follows:

Plastic Pipe Material Designation	Hydrostatic Design Basis at 73°F (23°C), psi (MPa)
PA 32312	2500 (17.2)
PE 2406	1250 (8.6)
PE 3408	1600 (11.0)
PVC 1120	4000 (27.6)
PVC 2110	2000 (13.8)
PVC 2116	3150 (24.8)

X2.3.2 The design stresses for natural gas at service temperatures above 73°F (23°C) should be based on hydrostatic design basis of the pipe that are applicable for the particular use temperature.

X2.3.3 The design stress for PE pipe for fuel gases other than natural gas should be based on hydrostatic design basis categories that have been established with the intended gas as the pressurizing medium (see X.2.7.2 for information on the effect of common LPG fuels on the long-term strength of PE pipes).

NOTE X2.2—Water may be used in lieu of a particular fuel gas where previous tests have shown that the results obtained with water are equivalent.

X2.3.4 Strengths for other plastic pipe materials will be added when these materials are included in the applicable ASTM specifications. The design stresses for natural gas are obtained by multiplying the hydrostatic design basis by design factors or service factors according to the class of location as described in Chapter IV of the American National Standard Code for Pressure Piping ANSI B31.8, or, for gas operators in the United States, Subpart C of the Minimum Federal Safety Standards for Transportation of Natural and Other Gas by Pipeline, Title 49, Code of Federal Regulations.

X2.3.5 For liquefied petroleum gas (LPG) applications, a maximum operating pressure of 30 psig (206 kPa) is recommended in NFPA 58 by the members of the National Liquefied Petroleum Gas Association. Liquefied petroleum gas has a higher condensation temperature than does natural gas; this maximum pressure is recommended to ensure that plastic pipe is not subjected to excessive exposure to LPG condensates. (See X2.7.1.)

X2.4 Thermal Stress

X2.4.1 Calculate the longitudinal stress (theoretical) induced in a pipe member between fixed points as follows:

$$S = E \times C \times \Delta t \quad \text{(X2.5)}$$

where:
S = stress, psi (MPa),
E = modulus of elasticity, psi (MPa), instantaneous, at 73°F (23°C),
C = coefficient of expansion, in./in./°F, (mm/mm/°C), and
Δt = maximum temperature minus minimum temperature, °F (°C).

X2.4.1.1 The measured stress has been determined to be less than that calculated. This difference is caused by the stress relaxation in viscoelastic materials.

X2.4.2 Calculate the theoretical force sustained at the fixed points (typically joints) in a pipe member as follows:

$$F = S \times A \quad \text{(X2.6)}$$

where:
F = force, lbf (N),
S = stress, psi (MPa), and
A = cross-sectional pipe wall area, in. ^{2} (mm^2).

X2.4.3 Calculate pipe contraction in unrestrained pipe caused by a reduction in temperature as follows:

$$\Delta L = k \times L \times C \times \Delta t \quad \text{(X2.7)}$$

where:
ΔL = change in length,
k = 1000 for ΔL (mm), L (m), C ($°C^{-1}$), Δt (°C), or
k = 12 for ΔL (in.), L (ft), C ($°F^{-1}$), Δt (°F),
L = original length,
C = coefficient of linear expansion, and
Δt = temperature change.

X2.5 Installation Procedure

X2.5.1 It is recognized that certain minimum requirements exist for the support of earth loads from backfill and other external forces. Proper installation techniques can be used with flexible conduit (as defined by Marston and Spangler **(2)**) to support relatively large earth loads without excessive deflection by mobilizing lateral passive soil forces. Proper installation technique ensures that the necessary passive soil pressure at the side of the pipe will be developed and maintained. It is also recognized that internal pressures may be valuable in minimizing the deflection caused by earth loads. Installation procedures described in Recommended Practice B 2774, ANSI B31.8, and the AGA Plastic Pipe Manual for Gas Service are recommended.

X2.5.2 Unrestrained plastic pipe expands and contracts from thermal change significantly more than metallic pipe. This ratio may be of the magnitude of ten to one. Typical coefficients of thermal expansion for unrestrained pipe are as follows (see Note X2.3):

PE 9.0×10^{-5}(in./in.)/°F 24.30 (mm/mm)/°C
PVC 3.5×10^{-5}(in./in.)/°F 11.45 (mm/mm)/°C

Mains and service lines installed by insertion are considered to approximate unrestrained conditions inside the casing pipe except at end connections. Direct-burial pipe is considered to be partially restrained by passive soil pressures except in the vicinity of joints.

NOTE X2.3—Coefficient of thermal expansion for the specific pipe being considered should be used, if available.

X2.5.3 Internal pressure, earth settlement, ground movement, and thermal contraction impose stresses on the pipe that can be transmitted to joints. These stresses are additive. Installation practices should reflect the need for continuous support and containment of the pipe through suitable bedding and backfilling procedures. Attention should be given to all joints, particularly to transition joints between plastic and metal pipe.

X2.5.4 It is desirable to have pipe joints that are as strong as the pipe itself in the longitudinal (axial) direction. Thermal fusion, solvent cement joints, and mechanical joints outlined in 6.10, Category 1 can provide such joint strength. The joint strength is a function of the assembly procedure, the design of the fitting, and the pipe material and dimensions (see X2.5.5).

X2.5.5 For those mechanical devices that are not designed to restrain the pipe against pullout forces, provisions must be made in the field to prevent pullout, keeping in mind that mechanical joints are vulnerable to the effects of internal pressure, temperature changes, earth settlement, and ground movement. A somewhat limited alternative is to use long sleeve-type fittings that permit limited movement without loss of pressure seal. Otherwise, provisions must be made in the field to prevent pullout through suitable anchoring at the joint.

X2.5.6 Plastic pipe joined with mechanical connectors that utilize a compression-type gasket must be reinforced by means of a tubular stiffener that extends at least under the section of pipe being compressed by the gasket and the gripping device (where used). The stiffener shall be nonsplit-type design to meet the performance requirements recommended by the manufacturer of the fitting in which it is used, and the joint shall meet the test requirements outlined in 6.10.

X2.5.7 Kinks found in the pipe shall be cut out. Pipe with kinks shall not be placed in service.

X2.6 Repair Considerations

X2.6.1 Repairs may be made to plastic pipe under appropriate circumstances. Selection and installation considerations for the use of full encirclement band clamps are available in ASTM Guide F 1025. Additional information on repair of plastic pipe may be found in manufacturers' literature, the A. G. A. Plastic Pipe Manual for Gas Service, ANSI B31.8 Gas Transmission and Distribution Piping Systems, and in the ASME Guide for Gas Transmission and Distribution Piping Systems.

X2.7 Environmental Effects

X2.7.1 *Natural Gas*—The long term effect of natural gas (methane, but with minor amounts of other gases) at 73°F (23°C) has been shown (**3,4**) to be essentially equivalent to that of water at 73°F (23°C) for three kinds of plastic pipe (PVC, PB, and PE). However, the effects of other liquid environments such as antifreeze agents, odorants, and hydrocarbons are known to be deleterious to some plastics, particularly when under service conditions, and therefore, should not be permitted in the gas system unless the plastic pipe has been fully evaluated under the service conditions.

X2.7.2 *Other Fuel Gases*— In accordance with this specification, PE materials must have not less than a 1250 psi HDB for 73.4°F, for methane. It has been shown (**5, 6,** and **7**) that aliphatic gaseous fuels of higher molecular weights than methane (natural gas) somewhat reduce the long-term strength of PE pipe materials compared to when using methane or water as the pressurizing medium. The reduction in PE's long-term strength caused by gaseous propane, propylene and butane is modest, well under 20 %. On this basis one report (**5**) considers an HDB of 1000 psi, for 73.4°F, as a reasonable and conservative design basis for PE piping materials intended for LPG fuel gas service.

X2.7.2.1 However, it has also been shown by the above referenced studies that propane, propylene and butane, when in the liquid phase, can cause a greater reduction in long-term strength, up to 40 %. Accordingly, the use of PE piping to convey LPG gaseous fuels should recognize this effect and the design and operation of such piping should consider the possibility for the occurence of condensates. Extensive experience has shown that the NFPA maximum recommended operating pressure of 30 psig for LPG systems (see X2.3.4) both minimizes the possible occurence of condensates and gives adequate consideration of the effect of LPG fuels on the long-term strength of PE piping.

NOTE X2.4—PPI Technical Report TR 22–88 (**5**) lists maximum operating pressures for various minimum operating temperatures at which condensates will not form in LPG systems in which the primary fuels are propane and butane.

X3. GAS PRESSURE PIPE AND FITTINGS PRODUCED FROM POLYETHYLENE (PE) MATERIALS WITH MINIMUM REQUIRED STRENGTH (MRS) DESIGNATION

X3.1 Scope

X3.1.1 This appendix covers information for PE pipe and fittings produced from polyethylene material with MRS designations. The intent for this Appendix is to utilize the information as a guideline for specifying product to take to the DOT (Department of Transportation). In conjunction with this Appendix, the AGA-PMC (American Gas Association Plastics Materials Committee) has a project to petition the DOT for recognition and use of MRS rated materials in gas pressure pipe and fittings. Gas utilities may obtain waivers from appropriate governing bodies to use MRS rated materials in gas pressure pipe and fittings. The non-mandatory information in this Appendix may be used to supplement requirements in the main body and Annex A1 of this specification.

X3.2 Referenced Documents

X3.2.1 *ISO Documents*:

ISO 9080 Thermoplastics Pipes for the Transport of Fluids—Methods of Extrapolation of Hydrostatic Stress Rupture Data to Determine Long-Term Hydrostatic Strength of Thermoplastic Pipe Materials

ISO 12162 Thermoplastic Materials for Pipes and Fittings for Pressure Applications—Classification and Designation—Overall Service (Design) Coefficient

X3.2.2 *PPI Documents*:

TR-3 Policies and Procedures for Developing Hydrostatic Design Basis (HDB), Pressure Design Basis (PDB), Strength Design Basis (SDB), and Minimum Required Strengths (MRS) Ratings for Thermoplastic Piping Materials or Pipe

TR-4 PPI Listing of Hydrostatic Design Basis (HDB), Strength Design Basis (SDB), Pressure Design Basis (PDB) and Minimum Required Strength (MRS) for Thermoplastic Piping Materials or Pipe

TR-33 Generic Butt Fusion Joining for Polyethylene Gas Pipe

TN-7 Nature of Hydrostatic Stress Rupture Curves

TABLE X3.1 Specification D 3350 Cell Classifications of Polyethylene Pipe and Fittings Materials

Physical Properties	PE Material Designation Code	
	PE 80	PE 100
Density	2, 3 or 4	3 or 4
Melt index	3 ,4, or 5	3, 4, or 5
Flexural modulus	3, 4, 5, or 6	4, 5, or 6
Tensile strength	3, 4, or 5	4, 5, or 6
Slow crack growth resistance (PENT)	6	6
Hydrostatic strength classification	3 or 4 and 5	4 and 6

TABLE X3.2 Pipe Category

Property	Test Method	A	B	C	D	E	H	I	J	K	L
Temperature, °F (°C)	…	100 (38)	120 (49)	140 (60)	160 (71)	180 (82)	…	…	…	…	…
Minimum Required Strength (MRS)	ISO 12162	…	…	…	…	…	3.2	4.0	6.3	8.0	10.0
Melt Index	D 1238	> 0.5	0.2 to 0.5	0.01 to 0.3	< 0.01[A]	0.07 to 0.20[B]	…	…	…	…	…

[A] Typically melt flow measured under condition 190/21.6 is less than 4.01 g/10 min.

[B] When a PE pipe or fitting is marked per 7.2 or 7.3 with this melt index range, it affirms that the manufacturer has verified generic fusion joining in accordance with PPI TR-33. Information about manufacturers who have verified PPI TR-33 generic fusion joining with their products is found in PPI TR-33. Consult PPI and the manufacturer for additional information.

NOTE X3.1—For more information on hydrostatic strength classification, refer to PPI TN-7 or contact the Hydrostatic Stress Board Chairman.

X3.3 Terminology

X3.3.1 *long-term hydrostatic strength (σ_{LTHS}), n*—a quantity obtained in accordance with ISO 9080 with the dimensions of stress which represents the predicted mean strength at a temperature θ and time *t* and can be considered as a property of the material under consideration.

X3.3.2 *lower predictive limit (LPL), n*—a pipe material's 97.5 % lower confidence level of the extrapolated value (typically at 20°C and 50 years) obtained in accordance with ISO 9080.

X3.3.3 *minimum required strength (MRS), n*—the categorized lower predictive limit (LPL) of the ISO 9080 long-term strength at 20°C and 50 years as defined in ISO 12162.

NOTE X3.2—MRS (θ, *t*) at 23°C would be required in developing operating pressures for gas lines under current DOT regulations, and that additional MRS ratings at 100°F (38°C), 120°F (49°C) or 140°F (60°C) would be required for gas use at elevated temperatures.

X3.3.4 *ISO thermoplastic material designation code, n*—the type of plastic (PE) followed by the minimum required strength (MRS) designation times 10. For example, a PE material with a MRS 8 designation has a material code of PE 80 and a PE material with a MRS 10 designation has a material code of PE 100.

X3.4 Materials

X3.4.1 Materials with PPI recommended MRS ratings are listed in PPI TR-4. Grades of recommendation and data requirements for PPI recommended MRS ratings are specified in part B of PPI TR-3.

X3.4.2 *Classification*— Polyethylene materials suitable for use in the manufacture of pipe and fittings under this specification may be classified in accordance with Specification D 3350 as noted in Table X3.1.

X3.4.3 Substantiation of long-term hydrostatic strength at 50 years is not required when the MRS time, *t*, is 50 years or greater. However, the manufacturer shall assure that in determining MRS at θ = 23°C and *t* = 50 years, any ductile to brittle transition occurs after the 50-year intercept.

X3.5 Requirements

X3.5.1 *Elevated Temperature Service* —In addition to MRS classification using the ISO 12162 standard conditions of 20°C and 50 years, the MRS can be determined at other desired temperature or time conditions as denoted by MRS (θ, *t*). The MRS (θ, *t*) is the categorized MRS value for a material at a temperature of θ °C and a time of *t* years. Consult the manufacturer for elevated temperature MRS values. In addition to the pipe category per table 4 of ASTM D 2513, the pipe category using the MRS designation as noted in Table X3.2 may be used.

NOTE X3.3—MRS (θ, *t*) categorized values may be published in PPI TR-4. For Pipe Category Table X3.2, in order to be consistent with the elevated temperature service requirements in 5.6 and Table 4, the MRS at the maximum service temperature (θ) is based upon a time (t) of 100, 000 h (11 years).

X3.5.2 *Sustained Pressure* —Sustained pressure testing should be preformed either per X3.5.2.1 or X3.5.2.2.

X3.5.2.1 *Testing at 73°F (23°C)*—The pipe or system should not fail in less than 1000 h when tested in accordance with Test Method D 1598. For PE 80/PE 2406 materials, the stress should be 1320 psi; for PE 80/PE 3408 materials, the stress should be 1600 psi; and for PE 100/PE 3408 materials, the stress should be 1600 psi.

NOTE X3.4—PE 80 material can be either PE 2406 or PE 3408; PE100 material is PE 3408.

X3.5.2.2 *Testing at 176°F (80°C)*—Alternatively, the sustained pressure testing may be performed at 176°F (80°C) under the following stress and minimum failure times as noted in Table X3.3.

NOTE X3.5—The intent of this test is to achieve a non-ductile failure mode. If a ductile failure is obtained, the test should be redone at the next lowest stress.

X3.6 Marking

X3.6.1 *Material Designation*—The ISO thermoplastic material designation code PE 80 or PE 100 may be utilized for material designation in addition to PE 2406 or PE 3408.

TABLE X3.3 Hydrostatic Strength—176°F (80°C) Stress/Minimum Failure Time Correlation

PE 80	PE 80	PE 100	PE 100
Stress, psi (MPa)	Minimum Failure Time, h	Stress, psi (MPa)	Minimum Failure Time, h
667 (4.6)	165	798 (5.5)	165
653 (4.5)	219	783 (5.4)	233
638 (4.4)	283	769 (5.3)	332
624 (4.3)	394	754 (5.2)	476
609 (4.2)	533	740 (5.1)	688
595 (4.1)	727	725 (5.0)	1000
580 (4.0)	1000		

X3.6.2 *Elevated Temperature Service* —Pipe intended for natural gas service at elevated temperatures greater than 73°F (23°C) may be marked with the three letter code from Table X3.2 in addition to the three letter code from Table 4.

REFERENCES

(**1**) Allman, W.B., "Earthloading Design Considerations for Polyethylene Gas Distribution Systems," *Proceedings of the Fifth Plastic Pipe Symposium*, November 13–15, 1974, Houston, TX, A.G.A., 1515 Wilson Blvd., Arlington, VA 22209, pp. 55–171.

(**2**) Spangler, M.G., "Secondary Stresses in Buried High Pressure Lines," *Iowa State College Bulletin*, Engineering Report 23 of the Iowa Engineering Experiment Station, 1954, 1955.

(**3**) Kuhlman, H. W., Leninger, R. I., and Wolter, Fritz, "Investigation of Engineering and Design Concepts for Plastics Pipe for Gas Distribution Application," presented at ANSI B31.8 meeting in St. Charles, IL, October 19, 1965.

(**4**) Palermo, E. F., and Cassady, M. J., "Comparison of Long-Term Effect of Water and Methane on PE 2306 and PE 3406 Pipe Performance," presented at the American Gas Association Plastic Material Committee Winter Workshop, February 23, 1982.

(**5**) "Polyethylene Plastic Piping Distrbution Systems for Components of Liquified Petroleum Gases," *PPI Technical Report TR-22.*

(**6**) Henrich, R.C., "Use of Polyethylene Pipe for Propane Distribution Systems," Fifth Fuel Gas Pipe Symposium, Houston, TX, November, 1974.

(**7**) Viebke, J., Tranker, T., Hedenquist, and Gedde, V.W., "Long-Term Behavior of MDPE Gas Pipes Exposed to Realistic Propane Environments," Thirteenth Fuel Gas Pipe Symposium, San Antonio, TX, November, 1993.