PART F. POLYETHYLENE SPECIFIC POLICIES, PRACTICES AND PROCEDURES

F.1 SUBSTITUTION OF THERMAL STABILIZERS IN PE PLASTICS PIPE COMPOUNDS

Permitted Thermal Stabilizer Changes Without Need for Additional Testing

F.1.1 PE Compounds with a Recommended HDB up to 140°F

Thermal stabilizers designed for use in polyethylene (PE) compounds may be used interchangeably in a PE plastic pipe formulation provided:

F.1.1.1 Thermal stability requirements in ASTM Standard D 3350, "Standard Specification for Polyethylene Plastics Pipe and Fittings Materials", are met;

F.1.1.2 The total content of the stabilizer package in the formulation is less than 0.5 parts per 100 parts of resin;

F.1.1.3 The quantity of the substituted stabilizer is within ±50 percent of the level of the stabilizer in the original formulation.

F.1.1.4 The quantity of the substituted thermal stabilizer does not exceed 0.25 parts per 100 parts of resin.

The compound with the stabilizer change does not become a new base compound to which additional changes can be made.

F.1.2 PE Compounds with a Recommended HDB at 180°F

F.1.2.1 Thermal stabilizers may be substituted provided they are chemically equivalent (same CAS#) to those used in the original formulation.

Proposed substitutions outside these guidelines may be evaluated in accordance with other policies and procedures in PPI TR-3.

F.2. VARIATION IN AMOUNT OF STABILIZER IN POLYETHYLENE PLASTICS PIPE COMPOUNDS

F.2.1 PE Compounds with a Recommended HDB up to 140°F

In the case of a polyethylene (PE) pipe compound at the E-6 Grade or higher, the amount of stabilizer may be changed up to ± 50 percent from the specified amount for the base composition without the need to submit additional hydrostatic strength data, provided the so altered composition satisfies the thermal stability requirements in ASTM Standard D 3350, "Standard Specification for Polyethylene Plastics Pipe and Fitting Materials".

The compound with the stabilizer change does not become a new base compound to which additional formulation changes can be made.

F.2.2 PE Compounds with a Recommended HDB at 180°F

Changes to the amount of stabilizer in a polyethylene (PE) pipe compound with a recommended HDB at 180°F are considered to be a new compound subject to the full testing requirements of Part A, and Part F.4. However, the HSB will review, on a Special Case basis, a request to consider different testing requirements upon review of the proposed modification.

F.3 SUBSTITUTION OF ULTRAVIOLET LIGHT STABILIZERS IN NON-BLACK POLYETHYLENE PLASTICS PIPE COMPOUNDS

Permitted Ultraviolet Light Stabilizer Changes Without Need for Additional Testing

F.3.1 PE Compounds with a Recommended HDB up to 140°F

Ultraviolet (UV) light stabilizers designed for use in non-black polyethylene (PE) compounds may be used interchangeably in a polyethylene plastic pipe formulation provided:

F.3.1.1 The total content of the UV stabilizer package in the formulation is less than 0.75 parts per 100 parts of resin;

F.3.1.2 The quantity of the substituted stabilizer does not exceed 0.75 parts per hundred.

The compound with the stabilizer changes does not become a new base compound to which additional changes can be made.

F.3.2 PE Compounds with a Recommended HDB at 180°F

F.3.2.1 Ultraviolet light stabilizers may be substituted provided they are chemically equivalent (same CAS#) to those used in the original formulation.

Proposed substitutions outside these guidelines may be evaluated with other policies and procedures in PPI TR-3. No consideration is given to the effectiveness in UV light protection in that this characteristic of the compound is not considered by PPI nor ASTM pipe standards and is between the purchaser and seller.

F.4 DETERMINATION AND VALIDATION OF THE HYDROSTATIC DESIGN BASIS (HDB) FOR POLYETHYLENE PIPING MATERIALS

Part F.4 offers several methods to validate that the stress regression curve extrapolation will continue in a linear manner to at least 100,000 hours. A recommended HDB at 73°F will not be given to a material that does not validate the ductile stress regression extrapolation.

For a 73°F HDB it is most common to use the Part F.4.1, Table F.4.1.1 for validation. For a recommended HDB at 140°F, any of the methods may be appropriate – Table F.4.1.2, Part F.4.2, or Part F.4.3 – depending on the material and the chosen test conditions. If brittle failures occur at the temperature for which an HDB is desired before 10,000 hours, then Part F.4.4 shall be used to determine the elevated temperature HDB. **For PE Compounds with a recommended HDB at 180°F, Part F.4.5 shall be used.**

F.4.1 Standard Method - Validation of HDB

Develop data in accordance with Part A for the temperature at which an HDB is desired. **If a brittle failure occurs before 10,000 hours, this standard method is not applicable and Part F.4.4 must be used to establish the elevated temperature LTHS and HDB.**

F.4.1.1 Analyze the data to determine the linear regression equation. Extrapolate this equation to 100,000 hours to determine the LTHS. If the 97.5% LCL at 100,000 hours is less than 90% of this LTHS, consider the data unsuitable for use by this method. If all conditions are satisfied, use Table 1 of ASTM D 2837 to determine the HDB category at this temperature.

F.4.1.2 When the HDB category has been determined by section F.4.1.1, use tables F.4.1.1 or F.4.1.2 to define the time and stress requirements needed to validate this HDB.

Test at least six specimens at the stress level determined by the tables. These specimens must have a minimum log average time exceeding the value shown in the table to validate the HDB. For example, to validate an HDB of 1000 psi at 140ºF, this required time is 3800 hours at 193ºF (90ºC)/690 psi or 11,300 hours at 176ºF (80ºC)/775 psi.

If a temperature/stress condition in the table results in a premature ductile failure for a particular PE material, the stress at that temperature may be lowered by 15%. The corresponding required time for this lowered stress is then six times the value in the table. For example, when validating an HDB of 1600 psi at 73°F, if testing at 80°C/825 psi results in ductile failures, lower the stress to 700 psi and retest. The required time to validate using this condition is now 1200 hours. If ductile failures still occur, the stress may be lowered to 595 psi and the corresponding time is increased to 7200 hours.

If a temperature/stress condition in the table results in a premature ductile failure for a particular PE material, the stress at that temperature may also be lowered by less than 15%. In this case, consult with the HSB Chairman to determine the appropriate required time at the selected stress level.

Table F.4.1.1

Validation of 73°F (23°C) HDB

HDB to be Validated (psi)	193°F (90°C)		176°F (80°C)	
	Stress (psi)	Time (hrs.)	Stress (psi)	Time (hrs.)
1600	735	70	825	200
1250	575	70	645	200
1000	460	70	515	200
800	365	70	415	200
630	290	70	325	200
500	230	70	260	200

Table F.4.1.2

Validation of 140°F (60°C) HDB

HDB to be Validated (psi)	193°F (90°C)		176°F (80°C)	
	Stress (psi)	Time (hrs.)	Stress (psi)	Time (hrs.)
1250	860	3800	970	11300
1000	690	3800	775	11300
800	550	3800	620	11300
630	435	3800	490	11300
500	345	3800	390	11300
400	275	3800	310	11300

Note: When an elevated temperature HDB is validated by this standard method, all lower temperature HDB's are considered validated for that material.

F.4.2 Rate Process Method (RPM) Validation of the HDB

Develop data in accordance with Part A for the temperature at which an HDB is desired. If a brittle failure occurs before 10,000 hours, or if the HDB does not validate using this RPM protocol, then the HDB may be determined using Part F.4.4.

1. Select an elevated temperature to test the PE pipe specimens. The maximum temperature chosen should not be greater than 203°F (95°C).
2. Select a stress at this temperature at which all failures occur in the slit mode (a crack through the pipe wall with no visible evidence of material deformation). Test at least six pipe specimens at this Condition I until failure. Ideally, the selected stress should result in failure times of about 100 to 500 hours.
3. At the same temperature, select another stress about 75 to 150 psi lower than for Condition I. Test at least six specimens at this Condition II until failure. Ideally, the selected stress for Condition II should result in failure times of about 1,000 to 5,000 hours.
4. Select a temperature 18°F (10.0°C) to 36°F (20.0°C) lower than Condition I and use a stress approximately the same stress as for Condition I. Initiate testing for six specimens at this Condition III. Ideally, the selected temperature for Condition III should result in specimens that are on test for at least 1,000 to 5,000 hours.
5. To validate the ASTM D 2837 long-term hydrostatic strength (LTHS) on a given material lot at a desired temperature, use the 12 data points from Conditions I and II, and the value of the LTHS at 100,000 hours determined at the desired temperature as determined from method D 2837. Using all these points, calculate the A, B, and C coefficients for the following three-coefficient rate process method equation:

6. Using this model, calculate the mean estimated failure time for Condition III. When the log average time on test for the six specimens tested at Condition III have reached this time, the ASTM D 2837 extrapolation to 100,000 hours to obtain the LTHS at the desired temperature has been validated.

$$\log t = A + \frac{B}{T} + \frac{C \log S}{T}$$

where: t = time, hours
T = absolute temperature, °K (°K = °C + 273)
S = hoop stress, psi
A, B, C = constants

F.4.3 ISO 9080 Based Method for Validation of 140°F (60°C) HDB

F.4.3.1 Develop data in accordance with Part A for the temperature at which an HDB is desired. Analyze the data to determine the linear regression equation as per ASTM D 2837. Extrapolate this equation to 100,000 hours to determine the LTHS. If the 97.5% LCL at 100,000 hours is less than 90 % of this LTHS, consider the data unsuitable for use by this method.

If a brittle failure occurs before 10,000 hours, this method is not applicable and Part F.4.4 shall be used to establish the elevated temperature HDB.

F.4.3.2 Develop a regression based on ductile stress-rupture data at either 80° or 90°C. Use Table F.4.3.2 to determine the appropriate data level for the temperature to be validated. The regression data must satisfy the following requirements:

F.4.3.2.1 The 97.5% LCL ratio for these data must be greater than 90%.

F.4.3.2.2 Non-failed specimens at the longest running times may be included in the regression, provided their inclusion does not decrease the LTHS (See ASTM D2837, section 5.2.2).

F.4.3.2.3 The log average of the five highest times (used in the regression) must exceed the minimum time t_{max} indicated in Table F.4.3.2.

Table F.4.3.2

Temperature to be Validated (°F)	193°F (90°C) Regression		176°F (80°C) Regression	
	Data Level[1]	Min. t_{max}[2]	Data Level[1]	Min. t_{max}[2]
140 (60°C)	E-6	5,500	E-10+	17,000

[1] Per data interval requirements
[2] t_{max} = log average of 5 longest times (included in regression)

See example below.

EXAMPLE:

140°F (60°C) regression data are determined in accordance with Part A and support an HDB of 1000 psi. No brittle failures are obtained within 10,000 hours.

According to Table F.4.3.2, minimum data requirements for a 193°F (90°C) regression are an "E-6" data level (Part A) and a t_{max} of 5,500 hours. The following data are obtained:

Stress (psi)	Failure Time (hrs)	Failure Mode
760	71	Ductile
755	102	Ductile
745	514	Ductile
740	693	Ductile
740	717	Ductile
735	908	Ductile
730	1478	Ductile
730	1726	Ductile
725	2155	Ductile
720	2943	Ductile
720	4087	Ductile
715	4382	Ductile
710	5207	Ductile
705	5928	Ductile
700	6174	Ductile
700	7000	Non-Failure

LCL Ratio = 98.4% (> 90%)

Longest 5 times:

4382
5207
5928
6174
7000

Log Avg. **5667**

[5,667 > 5,500]

HDB is validated.

F.4.4 Determination of Elevated Temperature HDB When Brittle Failures Occur Before 10,000 hours.

If the previous methods to validate an elevated temperature (i.e. above 73°F) HDB are not appropriate for the material and test data, then use this alternate method to determine the elevated temperature HDB.

F.4.4.1 Develop data in accordance with Part A for the temperature at which an HDB is desired.

Using only the ductile failures, determine the linear regression equation. The failure point data must be spread over at least two log decades and meet the LCL requirements of section 1.1. The stress intercept at 100,000 hours using this equation is the "ductile" LTHS.

F.4.4.2 To determine the brittle failure performance, solve for the three coefficients of the rate process equation using steps 1-4 Part F.4.2, or another recognized rate process method protocol. All failures must be in the brittle mode. Data developed under ASTM D 2837 to validate a 73°F HDB can be used to solve for the three-coefficient equation as long as all specimens at the three conditions were tested to failure and resulted in brittle type failures. Use the failure points at the three conditions to solve for the three unknown coefficients.

Using this brittle failure model, calculate the stress intercept value at 100,000 hours for the temperature at which an HDB is desired. This resulting stress intercept is the "brittle" LTHS.

F.4.4.3 The LTHS used to determine the HDB category as per Table 1 in ASTM D 2837, shall be the lower value of the ductile failure LTHS from section 2.1 or this brittle failure LTHS.

Rate Process Equation:

$$\text{Log}\, t = A + \frac{B}{T} + \frac{C \,\text{Log}\, S}{T}$$

where:
t = time, hours
T = absolute temperature, °K (°K = °C + 273)
S = hoop stress, psi
A,B,C = constants

Note: The ISO 9080 four-coefficient model may be used if it has a better statistical fit to the data, subject to review of the HSB Chairman.

F.4.5 ISO 9080 Based Method for Validation of 180°F (82°C) HDB

For a polyethylene (PE) compound with a recommended HDB at 180°F, only a single method to validate that the stress regression curve extrapolation will continue in a linear manner to at least 100,000 hours is provided. However, the HSB will review, on a Special Case basis, a request to consider different testing requirements upon review of the proposed modification.

When an elevated temperature HDB is validated, all lower temperature HDB's are considered validated for that material.

F.4.5.1 Develop data in accordance with Part A for the temperature at which an HDB is desired. Analyze the data to determine the linear regression equation as per ASTM D 2837. Extrapolate this equation to 100,000 hours to determine the LTHS. If the 97.5% LCL at 100,000 hours is less than 90 % of this LTHS, consider the data unsuitable for use by this method.

If a brittle failure occurs before 10,000 hours, this method is not applicable and the material cannot be validated.

F.4.5.2 Develop a regression based on ductile stress-rupture data at 100°C or 110°C. **The temperature chosen must be at least 15°C below the melting point (Tm as measured by DSC per ASTM D3418) of the PE material.** Use Table F.4.5 to determine the appropriate data level for the temperature to be validated. The regression data must satisfy the following requirements:

F.4.5.2.1 The 97.5% LCL ratio for these data must be greater than 90%.

F.4.5.2.2 Non-failed specimens at the longest running times may be included in the regression, provided their inclusion does not decrease the LTHS (See ASTM D2837, section 5.2.2).

F.4.5.2.3 The log average of the five highest times (used in the regression) must exceed the minimum time t_{max} indicated in Table F.4.5.

Table F.4.5

Temperature to be Validated	**230°F (110°C) Regression**		**212°F (100°C) Regression**	
	Data Level[1]	Min. t_{max}[2]	Data Level[1]	Min. t_{max}[2]
180°F (82°C)	E-10	8,350	E-16+	25,000

[1] Per data interval requirements
[2] t_{max} = log average of 5 longest times (included in regression)

Note: The reader may find the calculation example in part F.4.3 useful.

F.5 Hydrostatic Design Basis Substantiation for PE Materials

When it is desired to show that a PE material has additional ductile performance capacity than is required by validation of the 73°F (23°C) time/stress curve to 100,000 hours, one of the following four procedures may be used to further substantiate that the stress regression curve is linear to the 50 year (438,000 hour) intercept. **Only F.5.4 shall be used to substantiate a PE material with a recommended HDB at 180°F.**

F.5.1 If the 140°F HDB has been validated by Part F.4.1 or F.4.3, then the 73°F extrapolation is considered to be substantiated linear to 50 years (438,000 hours).

F.5.2 Use the twelve data points from Condition I and II obtained from Alternate Method of ASTM D 2837 (rate process method), along with the 50 year (438,000 hour) 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 50 years (438,000 hours) is substantiated.

F.5.3 When the Standard Method of ASTM D 2837 (TR-3, Part F.4.1 or F.4.3) is used to validate the 73°F (23°C) HDB, linear extrapolation of the stress regression curve to 50 years (438,000 hours) is substantiated when the log average failure time of six test specimens at 176°F (80°C) surpasses 6000 hours, or at 193°F (90°C) surpasses 2400 hours at a stress of no more than 100 psi below where all failures are ductile. A ductile failure reference stress shall be established by 3 specimens all failing in the ductile mode at the same temperature.

F.5.4 If the 180°F HDB has been validated by Part F.4.5, then the 73°F extrapolation is considered to be substantiated linear to 50 years (438,000 hours).

NOTE 1 The Long-Term Hydrostatic Strength (LTHS) at 50 years is not to be used for pressure rating calculations. The maximum stress is still calculated using the HDB (with the appropriate design service factors) obtained from the LTHS at 100,000 hours.

PE materials meeting this additional substantiation of the 73°F (23°C) extrapolation shall be denoted by an asterisk (*) in PPI TR-4.

F.6 POLICY ON ESTABLISHING EQUIVALENCE OF MODIFIED PE PIPE COMPOSITIONS

The Independent listing holder of a polyethylene pipe compound with a **PPI Standard Grade recommended HDB up to 140°F,** or an MRS, may modify that compound provided that either 1) the changes are minor (per F.6.1), or 2) the listing holder submits test data (per F.6.3) to confirm that the modified compound has an equivalent HDB or MRS to the original compound at each listed temperature.

F.6.1 Minor modification(s) in PE compounds that require no testing and reporting to the HSB are covered in the following sections of TR-3:

Colorant changes	Part D.1
Thermal Stabilizer Substitution	Part F.1

Stabilizer Variations	Part F.2
UV Stabilizer Substitution	Part F.3

Except for changes covered in Parts F.1 – F.3, if any changes, described above, are made to the polyethylene (PE) pipe compound with a recommended HDB at 180°F, including colorant levels, the resultant is considered to be a new compound subject to the full testing requirements of Part A, and Part F.4. However, the HSB will review, on a Special Case basis, a request to consider different testing requirements upon review of the proposed modification.

F.6.2 Other modifications to the composition of a piping compound could significantly affect its long-term service life and will require hydrostatic test data to confirm the modified compound's HDB or MRS is unchanged, per F.6.3. Examples of such compositional modifications include:

Changes in color concentrate, which may include:

A change in pigment level or type not permitted in Part D, and/or A change in the concentrate carrier resin. The concentrate carrier resin is not considered to have changed if the following characteristics are the same as that of the carrier resin used in the original composition:

- nominal melt index and density
- polymer manufacturing process technology and catalyst system
- comonomer

Changes in PE resin manufacturing process or specifications.

Changes in the PE pipe compound manufacturing process.

It is recognized that a change in PE resin manufacturing process conditions will generally, but not always, result in no adverse change in long-term strength characteristics, provided the resin and compound are made to the same manufacturer's product specifications. The determination of which process change could affect long-term strength has to be determined by the listing company using the best judgment. Past experience can be a guide. Whenever there is reasonable suspicion, testing (per F.6.3) should be conducted to confirm that the compound's long-term strength characteristics have remained unchanged. Some examples of process changes that should be considered during the decision-making process include:

1. Changes in the type of manufacturing process.
2. The start-up of new reactors at existing or new plant sites.
3. Changes in the type of compounding equipment used in the pelletization process.

F.6.3 Test requirements to establish equivalence

For compound modifications determined to require test data, stress-rupture testing shall be developed on one (1) lot of the modified compound to confirm that all HDBs and MRSs assigned to the original compound are maintained, as detailed below.

F.6.3.1 HDB Equivalence

The minimum levels of data required are:

- E-2 per Part A at 73°F
- E-2 per Part A at the highest other listed temperature, if any
- Validation at the highest listed temperature
- If applicable, 50-year substantiation according to Part F.5

F.6.3.2 MRS Equivalence

An abbreviated data set (less than the full ISO 9080 data requirement) is acceptable to establish equivalence of a modified compound with MRS listing, provided the following conditions are satisfied (*Note: Modified compounds not meeting these criteria must be tested to the full requirements of ISO9080 to establish equivalence or a Special Case can be requested to present an alternate qualification requirement*):

- The original compound has a Standard Grade recommended HDB listing at 73°F.
- The modified compound meets Part F.6.1 requirements for HDB equivalence.
- The ISO 9080 data set used to establish the original compound's MRS listing consists of:
  - Data from only one lot
  - At least three temperatures (per B.1.2.1).
  - The 20°C /50-year LPL is based on *Type A* (ductile) failure mode

For compounds meeting the above criteria, test data on the modified compound shall be developed per ISO9080 and Part B.1.2, with the following exceptions:

- All observations must be generated from a single lot and on the same nominal pipe size used to generate the original data set.
- Minimum data levels (per Part A):
  - E-2 at 20 or 23°C
  - E-2 at a temperature between 40°C and 70°C (inclusive)
  - E-6 at 80ºC or above. Also, the log average of the 5 longest times (failure or non-failure) included in the LPL determination, shall exceed 5000 hours
- The ISO 9080 LPL (20°C, 50-years) of this abbreviated data set, must be based on "Type A" (ductile) mode and support the same MRS (per ISO 12162) as that of the original full data set.

Modifications that are not within the scope of those defined in this Part are considered to result in a new compound subject to the full testing requirements of Part A, and Part F.4. However, the HSB will review, on a Special Case basis, a request to consider different testing requirements upon review of the proposed modification.

F.7 REQUIREMENTS FOR POLYETHYLENE (PE) MATERIALS TO QUALIFY FOR A HIGHER DESIGN FACTOR

A PE material that meets the following requirements qualifies for a recommended design factor of 0.63. PE materials not meeting these requirements will have their HDS established as per Part D.7.

1. 50-year substantiation according to Part F.5.
2. Minimum slow crack growth performance by ASTM F 1473 of 500 hours as required by ASTM D 3350.
3. LCL/LTHS ratio of at least 90% as per ASTM D 2837.

These requirements apply to the PE material – meaning that all compounding ingredients and colorants are included matching the material formulation to be listed. The HDS calculated with this DF will be used to establish the pipe material designation code to be listed in TR-4.