UniStar
NUCLEAR ENERGY

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# UniStar Topical Report for the Use of High Density Polyethylene (HDPE) Pipe in ASME Section III, Class 3, Seismic Category I, Safety-Related Buried Water Pipe Applications

NON-PROPRIETARY

## Description of Revisions

| Revision | Section | Description |
|---|---|---|
| 0 | | Initial Issue |

# ABSTRACT

This Topical Report (TR) presents code compliance, acceptance criteria, analysis methods, and modeling techniques for the use of High Density Polyethylene (HDPE) pipe in ASME Section III, Division 1, Class 3, Seismic Category I, buried service and cooling water piping for the U.S. EPR™ to be built by UniStar Nuclear Energy or its partners. This Topical Report also includes the requirements for the procurement, fabrication, installation, examination, and testing of the piping.

Section 2.0 identifies industry codes and standards applicable to the design, analysis, material specification, fabrication, installation, inspection, and testing of buried HDPE piping.

Section 3.0 presents the HDPE piping stress analysis criteria and identifies the load definitions and load combinations used in the qualification of buried HDPE piping. This section also discusses the HDPE piping design to address issues related to HDPE materials such as material properties, Design Factor, range of applicable pipe sizes, and design conditions (pressure and temperature).

Section 4.0 focuses on the seismic analysis methods. This section presents buried HDPE piping requirements and soil-load interactions.

Section 5.0 presents pipe modeling techniques used for the qualification of HDPE piping.

Section 6.0 presents the HDPE pipe support design criteria for buried HDPE piping.

Section 7.0 provides installation requirements for buried HDPE piping.

Section 8.0 presents the inspection and test criteria applicable to the use of HDPE piping as described in this TR. This section includes requirements to perform non-destructive examinations (NDE), and fusion machine operator qualifications.

Section 9.0 addresses design life; including predicted service life, design for elevated temperatures, and fatigue loading. This section demonstrates the ability for HDPE pipe to safely operate for 60 years and beyond by use of the Rate Process Method (RPM).

Section 10.0 identifies Quality Control (QC) and Quality Assurance (QA) requirements. Material manufacturers, suppliers, fabricators and installers are required to maintain and implement a Quality Assurance Program.

Section 11.0 identifies the requirements and guidelines that a licensee is responsible to include in a COL application for the U.S. EPR™ to be built by UniStar Nuclear Energy or its partners.

Section 12.0 summarizes and presents conclusions.

Section 13.0 lists references used for the development of this Topical Report.

This Topical Report demonstrates that HDPE 4710 piping is suitable for buried pipe applications for a Design Pressure up to 200psig, a Design Temperature up to 140°F, and a 60-year service life. Approval for HDPE piping identified herein is requested for a period of 40 years, consistent with the license term of a Combined License.

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## Acronyms

| Acronym | Definition |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| ASME | American Society of Mechanical Engineers |
| ASTM | American Society for Testing and Materials |
| BPVC | Boiler and Pressure Vessel Code |
| CFR | Code of Federal Regulations |
| CCAB | Certified Certificate of Analysis for Batch |
| COLA | Combined Operating License Application |
| CofA | Certificate of Analysis |
| CPTR | Certified PE Test Report |
| DBA | Design Basis Accident |
| DF | Design Factor |
| DFL | Dynamic Fluid Loads |
| GDC | General Design Criterion |
| FPS | Fusion Procedure Specification |
| HDB | Hydrostatic Design Basis |
| HDS | Hydrostatic Design Stress |
| HDPE | High Density Polyethylene |
| ISO | International Standards Organization |
| ITAAC | Inspections, Tests, Analyses, and Acceptance Criteria |
| LTHS | Long-Term Hydrostatic Strength |
| MRS | Minimum Required Strength |
| MIC | Microbiologically Influenced Corrosion |
| NRC | Nuclear Regulatory Commission |
| NDE | Non-Destructive Examination |
| PDB | Pressure Design Basis |
| PE | Polyethylene |
| PPI | Plastic Pipe Institute |
| PQC | Product Quality Certification |
| PQR | Procedure Qualification Record |
| QA | Quality Assurance |
| QC | Quality Control |
| RG | Regulatory Guide |
| RPM | Rate Process Method |
| SAM | Seismic Anchor Movement |
| SDB | Strength Design Basis |
| SDR | Standard Dimension Ratio |
| SRP | Standard Review Plan |
| SRSS | Square Root Sum of the Squares |
| SSCs | Systems, Structures, and Components |
| SSE | Safe Shutdown Earthquake |
| TR | Topical Report |
| U.S. EPR™ | US Evolutionary Pressurized Water Reactor |
| UV | Ultra-Violet |

# 1.0 INTRODUCTION

This Topical Report (TR) presents code compliance, acceptance criteria, analysis methods, and modeling techniques for the use of High Density Polyethylene (HDPE) pipe in ASME Section III, Division 1, Class 3, Seismic Category I, buried service and cooling water piping for the U.S. EPR™ to be built by UniStar Nuclear Energy or its partners. This Topical Report also includes the requirements for the procurement, fabrication, installation, examination, and testing of the piping.

The use of HDPE piping will improve safety system availability and plant reliability by eliminating failure mechanisms that have historically been issues in steel piping water systems for operating nuclear power plants, such as erosion/corrosion and Microbiological Influenced Corrosion (MIC).

This TR is applicable to buried water system piping with a Design Pressure and Design Temperature up to 200psig and 140°F, respectively, with a possible transient temperature excursion up to 160°F for a period of 30 days. HDPE piping service life identified herein is requested for a period of 40 years. This 40 year time frame is selected to be consistent with the license term of the COL applicants. Straight pipe wall thickness ranges from a minimum standard wall of DR17 to a maximum standard wall of either DR6 or a thickness of 4.5 inches, whichever is thinner, and shall be calculated utilizing a DF of 0.5.

Only the following are permitted for construction of a buried PE piping system: straight PE pipe, three segment and five segment mitered elbows (made from PE pipe), PE flange adapters to metallic flanges (flange adapters may be either molded or machined from extra heavy wall pipe), and butt fusion joints.

This report is presented as follows:

Section 2.0 identifies industry codes and standards applicable to the design, analysis, material specification, fabrication, installation, inspection, and testing of buried HDPE piping.

Section 3.0 presents the HDPE piping stress analysis criteria and identifies the load definitions and load combinations used in the qualification of buried HDPE piping. This section also discusses the HDPE piping design to address issues related to HDPE materials such as material properties, Design Factor, range of applicable pipe sizes, and design conditions (pressure and temperature).

Section 4.0 focuses on the seismic analysis methods. This section presents buried HDPE piping requirements and soil-load interactions.

Section 5.0 presents pipe modeling techniques used for the qualification of HDPE piping.

Section 6.0 presents the HDPE pipe support design criteria for buried HDPE piping.

Section 7.0 provides installation requirements for buried HDPE piping.

Section 8.0 presents the inspection and test criteria applicable to the use of HDPE piping as described in this TR. This section includes requirements to perform non-destructive examinations (NDE), and fusion machine operator qualifications.

Section 9.0 addresses design life; including predicted service life, design for elevated temperatures, and fatigue loading. This section demonstrates the ability for HDPE pipe to safely operate for 60 years and beyond by use of the Rate Process Method (RPM).

Section 10.0 identifies Quality Control (QC) and Quality Assurance (QA) requirements. Material manufacturers, suppliers, fabricators and installers are required to maintain and implement a Quality Assurance Program.

Section 11.0 identifies the requirements and guidelines that a licensee is responsible to include in a COL application for the U.S. EPR™ to be built by UniStar Nuclear Energy or its partners.

Section 12.0 summarizes and presents conclusions.

Section 13.0 lists references used for the development of this Topical Report.

## 1.1 Definitions

Terms used in this Topical Report are given below:

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| Butt fusion pressure: | The calculated theoretical butt fusion pressure plus the drag pressure. This is the gauge pressure used by the butt fusion operator on the butt fusion machine to join the pipe ends. |
| Certificate Holder: | An organization holding a Certificate of Authorization or Certificate of Accreditation issued by ASME. |
| Certificate of Analysis: | A document attesting that Natural Compound, Pigment Concentrate Compound, or PE Compound is in accordance with specified requirements, including the actual results of all required tests and examinations. |
| Certified PE Test Report: | A document attesting that PE Material is in accordance with specified requirements, including the actual results of all required tests and examinations. |
| Co-extrusion: | An extrusion process that employs two or more extruders that simultaneously feed a common extrusion die to manufacture polyethylene pipe with external surface color stripes. |
| Component: | A vessel, concrete containment, pump, pressure relief valve, line valve, storage tank, piping system, or core support structure that is designed, constructed, and stamped in accordance with the rules of ASME Section III. |

Cool time under pressure: The time that the fusion pressure must be maintained before removing the pipe from the butt fusion machine.

Data Acquisition Recorder: An electronic device that automatically records information during the fusion process.

Data acquisition record: A detailed record of the fusion process.

Design Factor: A number less than 1.0 (which takes into consideration all the variables and degree of safety involved in thermoplastic pressure piping installations) which is multiplied by the Hydrostatic Design Basis (HDB) to give the Hydrostatic Design Stress (HDS).

DR (dimension ratio): The average outside diameter of a pipe divided by the specified minimum fabricated wall thickness ($t_{fab\ min}$).

Drag pressure: The pressure shown on the fusion machine gauge which is required to keep the carriage moving at its slowest speed. This is the combination of the drag resistance and the frictional resistance of the butt fusion machine.

Extruder: A machine for continuously producing a polyethylene shape having a constant cross section, such as pipe.

Extrusion: A manufacturing process by which lengths of constant shape and cross section such as pipe are formed by forcing an extrudate such as molten plastic through an extrusion die.

Extrusion die: An orifice containing element, mounted at the delivery end of an extruder that shapes the extrudate (molten polyethylene).

Frictional resistance in the butt fusion machine: Force necessary to overcome friction in the whole mechanism of the butt fusion machine.

Fusion Machine Operator: Person trained to carry out butt fusion joining between PE pipes and/or fittings based on the Fusion Procedure Specification (FPS).

Fusion Performance Qualification (FPQ): A certificate issued by the manufacturer that documents satisfactory demonstration of a butt fusion machine operator's qualifications and ability to produce fusion joints meeting prescribed standards.

Fusion Procedure Specification: A document providing in detail the required variables for the butt fusion process to assure repeatability in the butt fusion process.

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| HDPE | (High Density Polyethylene) Polyethylene with an ASTM D3350 Density Cell Class of 3 or higher |
| Heater bead-up size: | The size of a bead of PE formed between the pipe end and the heater surface during the butt fusion heating cycle. |
| Heater surface temperature: | The temperature of the surface of the coated heater plate. |
| Hydrostatic Design Basis: | One of a series of stress values for a PE compound established in accordance with ASTM D2837 and PPI TR-3 that is listed in PPI TR-4. |
| Hydrostatic Design Stress: | The estimated maximum tensile stress the material is capable of withstanding continuously with a high degree of certainty that failure of the pipe will not occur. This stress is circumferential when internal hydrostatic water pressure is applied. HDS = HDB x Design Factor. |
| IDR: | The average inside diameter of a pipe divided by the specified minimum fabricated wall thickness ($t_{fab\ min}$). |
| Interfacial pressure: | The pressure selected for butt fusion from the interfacial pressure range specified in the FPS. |
| Item: | A product constructed under a Certificate of Authorization or Accreditation, supports (NCA-3120), or material (NCA-1220). |
| Long-term Hydrostatic Strength: | Estimated tensile stress in the wall of the pipe in the circumferential orientation that when applied continuously will cause failure of the pipe at 100,000 hours. |
| Material Designation: | A naming convention for Polyethylene Compound consisting of the abbreviation for polyethylene, PE, followed by the ASTM D 3350 cell classification value numbers for density and slow crack growth resistance, followed by the hydrostatic design stress rating for water at 73°F as defined by PPI TR-4. |
| Modulus of soil reaction, E′: | The soil reaction modulus is a proportionality constant that represents the embedment soil's resistance to ring deflection of pipe due to earth pressure. |
| Natural Compound (NC): | A Polyethylene Source Material for Polyethylene Compound that does not contain black or color pigmentation. |

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| Natural Compound Manufacturer: | An organization that manufactures Natural Compound in accordance with Section III of the ASME Code, but does not manufacture Pigment Concentrate Compound. |
| Part: | An item which is attached to or becomes a portion of a component or support before completion and stamping of the component or support. Parts have work performed on them requiring verification by an Inspector. |
| Polyethylene (PE): | A plastic obtained by polymerizing ethylene gas. It is normally a translucent, tough, waxy solid which is unaffected by water and by a large range of chemicals. |
| PE Compound: | Natural Compound combined with Pigment Concentrate Compound. |
| PE Source Compound Manufacturer: | An organization that manufactures PE Compound but does not manufacture Pigment Concentrate Compound. |
| PE Lot: | The quantity shipped that is represented by the Certificate of Analysis or the Certified PE Test Report. The term “batch” rather than lot may appear on a Certificate of Analysis. |
| PE Material: | PE Compound manufactured into a product form, without joining. |
| PE Material Manufacturer: | An organization that uses either PE Compound or Natural Compound combined with Pigment Concentrate Compound to produce PE Material. |
| PE Material Supplier: | An organization that procures, receives, stores, and ships PE Material, but does not perform or subcontract any design, examination, testing, marking, or operations that affect the PE Material properties. |
| PE pipe: | PE Material in the form of un-fused lengths of pipe. |
| PE product forms: | Pipe, mitered elbows, and flanges. |
| PE Service Supplier: | An individual or organization that furnishes nondestructive examination, testing, or calibration services in accordance with a procurement document. |
| PE Source Material: | Products used for conversion to PE Material. Natural Compound, Pigment Concentrate Compound, and PE Compound are PE Source Materials. PE pipe is a |

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| | source material for other product forms such as pipe segments that are fused to form mitered elbows or pipe segments that are machined to form flange adapters. |
| PE Source Material Manufacturer: | A manufacturer of PE Source Material such as a Natural Compound Manufacturer, Pigment Concentrate Compound Manufacturer, PE Compound Manufacturer, or PE Material Manufacturer. |
| PENT | Test method known as PENT (Pennsylvania Notch Test). ASTM F1473 standard test method for notch tensile test to measure the resistance to slow crack growth of polyethylene pipes and resins. |
| Percent Ovality: | The allowed difference between the maximum measured diameter and the minimum measured diameter divided by the measured average outside diameter and multiplied by 100. |
| Pigment Concentrate Compound (PCC): | A compound made of PE with a high concentration of carbon black or colorant additives produced in accordance with the Natural Compound Manufacturer's formulation requirements. (This compound is often called "Master Batch") |
| Pigment Concentrate Compound Manufacturer: | An organization that manufactures Pigment Concentrate Compound in accordance with this Topical Report and a procedure provided by the Natural Compound Manufacturer. |
| Plastic extrusion (extrusion): | A process by which lengths of constant cross section material (pipe) are formed by forcing molten polyethylene through a die. |
| Resultant Moment: | The resultant moment is calculated per ND-3653.3 of ASME Section III. This includes all three moment components combined using the square root sum of squares (SRSS) method. |
| Stiffness factor: | The measurement of a pipe's ability to resist deflection as determined in accordance with ASTM D2412. |
| Supplier of Subcontracted Services: | An individual or organization that furnishes nondestructive testing, examination or calibration services in accordance with a procurement document. |
| Test coupon: | A specimen prepared from a butt fusion joint that is used to qualify butt fusion procedures or operator qualification. |

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| Test specimen: | A section of a butt fusion joint that is tested in accordance with a testing procedure to qualify a butt fusion machine operator or fusion procedure. |

# 2.0 CODES AND STANDARDS

2.1 ASME Boiler and Pressure Vessel Code

Design and analysis of ASME Class 3 piping for the U.S. EPR™ to be built by UniStar Nuclear Energy or its partners, is in accordance with the 2001 ASME Boiler and Pressure Vessel (B&PV) Code, Section III, Division 1, 2003 addenda. This is the design code for the HDPE piping addressed in this Topical Report with the restriction that the treatment of dynamic loads, including seismic loads, in the pipe stress analyses will be according to sub-articles ND-3650 of the 1993 Addenda of the ASME Code.

2.1.1 Section III, Division 1, Subsection ND

2.1.2 Section III, Division 1, Subsection NCA

2.1.3 Section V, Nondestructive Examination

2.1.4 Section XI, Rules for In-service Inspection of Nuclear Power Plants

2.1.5 B16.5-07, Pipe Flanges and Flanged Fittings: NPS 1/2 through 24

2.1.6 B16.47-06, Large Diameter Steel Flanges: NPS 26 Through NPS 60 Standard

2.2 ASTM Polyethylene (PE) Material Standards

2.2.1 D422-63(re-approved 07), Standard Test Method for Particle – Size Analysis of Soils

2.2.2 D638-08, Standard Test Method for Tensile Properties of Plastics

2.2.3 D698-07, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 $ft\text{-}lb_f/ft^3$)

2.2.4 D746-07, Standard Test Method for Brittleness Temperature of Plastics and Elastomers by Impact

2.2.5 D792-08, Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

2.2.6 D1140-00, Standard Test Method for Amount of Materials in Soils Finer than No. 200 Sieve

2.2.7 D1238-04c, Standard Test Method for Melt Flow Rates of Thermoplastics by Extrusion Plastometer

2.2.8 D1505-03, Standard Test Method for Density of Plastics by the Density-Gradient Technique

2.2.9 D1556-07, Standard Test Method for Density of Soil in Place by the Sand-Cone Method

2.2.10 D1557-09, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 $ft\text{-}lb_f/ft^3$)

2.2.11 D1598-02(re-approved 09), Standard Test Method for Time-to-Failure of Plastic Pipe under Constant Internal Pressure

2.2.12 D1603-06, Standard Test Method for Carbon Black Content in Olefin Plastics

2.2.13 D2216-05, Standard Method of Laboratory Determination of Moisture Content of Soil

2.2.14 D2290-08, Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe by Split Disk Method

2.2.15 D2412-02(re-approved 08), Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading

2.2.16 D2487-06, Classification of Soils for Engineering Purposes

2.2.17 D2774-08, Standard Practice for Underground Installation of Thermoplastic Pressure Piping

2.2.18 D2837-08, Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products

2.2.19 D3035-08, Standard Specification for PE Plastic Pipe (DR-PR) Based on Controlled Outside Diameter

2.2.20 D3261-10a, Standard Specification for Butt Heat Fusion Polyethylene (PE) Plastic Fittings for PE Plastic Pipe and Tubing

(D3261-10a is for molded fittings, and shall be used only for molded flange adapters)

2.2.21 D3350-10, Standard Specification for PE Plastics Pipe and Fittings PE compounds

2.2.22 D4218-96(re-approved 08), Standard Test Method for Determination of Carbon Black Content in PE Compounds by the Muffle-Furnace Technique

2.2.23 D4253-00(re-approved 06), Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table

2.2.24 D4318-05, Test Methods for Liquid Limit, Plastic Limit & Plasticity Index of Soils

2.2.25 D4883-08, Standard Test Method for Density of Polyethylene by the Ultrasound Technique

2.2.26 F412-09, Standard Terminology Relating to Plastic Piping Systems

2.2.27 F714-08, Standard Specification for PE Plastic Pipe (SDR-PR) Based on Outside Diameter

2.2.28 F1473-07, Standard Test Method for Notch Tensile Test to Measure the Resistance to Slow Crack Growth of PE Pipes and Resins

2.2.29 F1668-08, Standard Guide for Construction Procedures for Buried Plastic Pipe

2.2.30 F2164-02(re-approved 07), Standard Practice for Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Hydrostatic Pressure

2.2.31 F2206-02, Standard Specification for Fabricated Fittings of Butt-Fused PE Plastic Pipe, Fittings, Sheet Stock, Plate Stock, or Block Stock

2.2.32 ASTM F2263-09 Standard Test Method for Evaluating the Oxidative Resistance of PE Pipe to Chlorinated Water

2.2.33 F2620-09$^{\varepsilon 1}$ Standard Practice for Heat Fusion Joining of PE Pipe and Fittings, (Superscript $^{\varepsilon 1}$ is for minor March 2010 editorial Change)

2.2.34 F2634-07 Standard Test Method for Laboratory Testing of Polyethylene (PE) Butt Fusion Joints using Tensile-Impact Method

2.2.35 F2769-09, Standard Specification for PE of Raised Temperature (PE-RT) Plastic Hot and Cold-Water Tubing and Distribution Systems

2.3 Plastic Pipe Institute (PPI)

2.3.1 PPI TR-3-2008, Policies and Procedures for Developing Hydrostatic Design Basis (HDB), Pressure Design Basis (PDB), Strength Design Basis (SDB) and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe

2.3.2 PPI TR-4-2009, PPI Listing of Hydrostatic Design Basis (HDB), Hydrostatic Design Stress (HDS), Strength Design Basis (SDB), Pressure Design Basis (PDB) and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe

2.3.3 PPI Technical Report TR-33-2006, Generic Butt Fusion Joining Procedure for Field Joining of PE Pipe

2.3.4 PPI TN-16-2008 Rate Process Method for Projecting Performance of PE Piping Components

2.3.5 PPI TN-38-2007 Bolt Torque for PE Flanged Joints

2.3.6 PPI TN-42-2009 Recommended Minimum Training Guidelines for PE Pipe Butt Fusion Joining Operators for Municipal and Industrial Projects

2.4 International Standards Organization (ISO)

2.4.1 ISO TR 19480-2005, Thermoplastics pipes and fittings for the supply of gaseous fuels or water – Guidance for training and assessment of fusion operators

# 3.0 PIPING STRESS ANALYSIS CRITERIA

## 3.1 Piping Seismic Classifications

This Topical Report pertains to buried piping classified as Seismic Category I, which in accordance with Regulatory Guide (RG) 1.29, "Seismic Design Classification," is required to be designed to withstand the effects of a Safe Shutdown Earthquake (SSE) and remain functional during and after the event.

## 3.2 Service Levels

The U.S. EPR™ to be built by UniStar Nuclear Energy or its partners utilizes the four Service Levels used in the ASME Code, Levels A, B, C and D, and testing conditions, in the design of piping. These four service level designations also have the alternate naming convention of Normal, Upset, Emergency and Faulted, respectively. Load cases have been developed for the four defined Service Levels based on the guidance in Standard Review Plan (SRP) 3.9.3. The general definitions of each of the four levels are as follows:

A. Level A (Normal)

Level A refers to sustained loadings encountered during normal plant/system start-up, operation, refueling and shutdown.

B. Level B (Upset)

Level B refers to occasional, infrequent loadings deviating from normal plant conditions, but having a high probability of occurrence. Piping and pipe supports will be designed to withstand these loading conditions without sustaining any damage or reduction in function.

C. Level C (Emergency)

Level C refers to infrequent loadings with a low probability of occurrence, which is considered as design basis loadings causing no significant loss of integrity. Such an occurrence requires the unit to be shut down for inspection and repair to any damaged components prior to re-start.

D. Level D (Faulted)

Level D refers to infrequent loadings with an extremely low probability of occurrence, associated with design basis accidents (such as Safe Shutdown Earthquake, Design Basis Pipe Break and Loss of Coolant Accident). Per Regulatory Guide 1.29, safety related SSCs must retain their ability where required to ensure:

1) The integrity of the reactor coolant pressure boundary,
2) The capability to shut down the reactor and maintain it in a safe shutdown condition,
3) The capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures comparable to the guideline exposures of 10 CFR Part 50.34(a)(1) or 10 CFR Part 100.11.

E. Testing

Pressure tests such as hydro tests are included in the piping analysis for primary membrane stresses.

## 3.3 Load Cases and Load Combinations

### 3.3.1 Loadings

A. Pressure

Internal design pressure, $P_D$, is used in the design and analysis of ASME Code Class 3 piping. Minimum pipe wall thickness calculations are performed utilizing design pressure. Design pressures and maximum service pressures are used in load combinations for calculating stresses for Design Conditions, Service Levels A, B, C and D and Testing.

B. Deadweight

Deadweight loads are calculated by applying a negative vertical acceleration to the pipe, contents, and in-line components (for unburied portion). Trench loads and water weight are also considered in the stress analysis.

C. Transportation Loading

The effects of vehicles (vehicles and railroads) driving over the buried piping are considered in the design and analysis.

D. Thermal Expansion

The effects on piping thermal expansion and contraction are considered in the design. Various operating modes are considered in order to determine the most severe thermal loading conditions. The zero thermal load temperature is taken as 70°F.

E. Seismic

The effects of seismic inertial loads and anchor movements are included in the design analysis. The design of the U.S. EPR™ Seismic Category I piping includes analysis of the inertial movements and building anchor movement (>1/16") as a result of a Safe Shutdown Earthquake (SSE). These loads are Service Level D loads.

F. Building Settlement Loadings

Loads due to the displacements of a building anchor or support over time are considered in the design and analysis.

G. Fluid Transient Pressure Surge Loadings

The effects of water hammer pressure surge loads are considered in the design and analysis of HDPE pipe and are limited as described in Section 3.10.4.

H. Hydro tests

Piping systems are tested for leaks by filling the system with the test fluid to test pressures.

3.3.2 Load Combinations

Using the methodology and equations from the ASME Code, pipe stresses are calculated for various load combinations. The ASME Code includes design limits for Design Conditions, Service Levels A, B, C and D and testing. Load combinations for Class 3 piping are illustrated in Table 3-2.

3.3.3 Design and Service Loading

Design loads are as defined in ASME Section III, ND-3112.1 through ASME Section III, ND-3112.3. Loads applied to buried PE piping system are specified in the Design Specification. Design Specification content shall include, but not be limited to, the following:

(a) Internal design pressure $P_D$, for pressure design in accordance with Sections 3.10 and 3.10.6.
(b) Maximum and minimum temperature, T, for the selection of allowable stress (Section 3.10, Section 3.12.1 and Section 9.4) and design for temperature effects in accordance with Section 3.12.1. The maximum Service Level A temperature is the Design Temperature, $T_D$ .
(c) Maximum flow velocity, v, and the stress limits for the pressure spike loads resulting from the maximum flow velocity, v.
(d) Vertical soil pressure due to earth loads, $P_E$, vertical pressure due to surcharge loads, $P_L$, pressure due to ground water, $P_{gw}$, including pressure resulting from saturated soil weight, surcharge, buoyancy and flotation, for design in accordance with Section 3.14.
(e) Permanent ground movement, soil settlement, for design as non-repeated anchor movements in accordance with Section 3.13 and 3.14.
(f) Seismic wave passage and seismic soil movement and building anchor motions for seismic design in accordance with Section 3.15.
(g) Ground movement caused by frost heave for design of expansion and contraction in accordance with Section 3.12.2.
(h) The duration of load for each load case. The PE pipe physical and mechanical properties are based on the duration of load.
(i) Consideration for the cumulative effect from loads of different duration.

Table 3-1: Design Conditions and Stress Criteria for Class 3 Piping

| Service Level | Stress Condition | Capacity Criteria |
|---|---|---|
| Design | Minimum Wall Thickness | Requirements of Section 3.10 |
| | Primary – Longitudinal Stress | Requirements of 3.11.1 with k = 1.0 |
| A | Primary – Sidewall Compression | $S_{comp}$, Table 3-12 (Section 3.14.2) |
| | Primary – Buckling due to External Pressure | Requirements of Section 3.14.3.A |
| | Primary – Flotation | Requirements of Section 3.14.4 |
| | Primary – Pressure | Less than 1.0 × $P_D$ |
| | Primary – Longitudinal Stress | Requirements of 3.11.1 with k = 1.0 |
| | Secondary – Thermal | 1100psi (Section 3.12.2.C) |
| | Non Repeated Anchor Motion | 2 × S (Section 3.13) |
| B | Primary – Sidewall Compression | $S_{comp}$, Table 3-12 (Section 3.14.2) |
| | Primary – Buckling due to External Pressure | Requirements of Section 3.14.3.A |
| | Primary – Flotation | Requirements of Section 3.14.4 |
| | Primary – Pressure | Less than 1.1 × $P_D$ |
| | Primary – Surge Pressure | 1.5 × $P_D$ |
| | Primary – Longitudinal Stress | Requirements of Section 3.11.1 or 0.4×Material Tensile strength at Yield |
| | Secondary – Thermal | 1100psi (Section 3.12.2.C) |
| C | Primary – Sidewall Compression | $S_{comp}$, Table 3-12 (Section 3.14.2) |
| | Primary – Buckling due to External Pressure | Requirements of Section 3.14.3.A |
| | Primary – Flotation | Requirements of Section 3.14.4 |
| | Primary – Pressure | Less than 1.33 × $P_D$ |
| | Primary – Surge Pressure | 1.5 × $P_D$ |
| | Secondary – Thermal | 1100psi (Section 3.12.2.C) |
| D | Primary – Sidewall Compression | $S_{comp}$, Table 3-12 (Section 3.14.2) |
| | Primary – Buckling due to External Pressure | Requirements of Section 3.14.3.A |
| | Primary – Flotation | Requirements of Section 3.14.4 |
| | Primary – Pressure | Less than 1.33 × $P_D$ |
| | Primary – Surge Pressure | 1.5 × $P_D$ |
| | Secondary – Thermal | 1100psi (Section 3.12.2.C) |
| | Secondary – Seismic | 1100psi (Section 3.15) |

Note: Terms are defined in Section 3.7

Table 3-2: Load Combinations

| Service Level | Stress Condition | Load Combination |
|---|---|---|
| Design | | $P_D$+DW |
| | | $P_D$ |
| A | Primary – Sidewall Compression | $P_E + P_L$ |
| | Primary – Buckling due to External Pressure | $P_E + P_L + P_{gw}$ |
| | Primary – Flotation | $W_W$ |
| | Primary – Pressure | $P_a$ |
| | Primary – Longitudinal Stress | $P_a$+DW |
| | Secondary – Thermal | Range ($T_{a\,min}$, $T_{a\,max}$) |
| | Non Repeated Anchor Motion | BS |
| B | Primary – Sidewall Compression | $P_E + P_L$ |
| | Primary – Buckling due to External Pressure | $P_E + P_L + P_{gw}$ |
| | Primary – Flotation | $W_W$ |
| | Primary – Pressure | $P_b$ |
| | Primary – Pressure + Surge Pressure | $P_b+P_{bs}$ |
| | Primary – Longitudinal Stress | $P_b$ + DW |
| | Secondary – Thermal | Range ($T_{b\,min}$, $T_{b\,max}$) |
| C | Primary – Sidewall Compression | $P_E + P_L$ |
| | Primary – Buckling due to External Pressure | $P_E + P_L + P_{gw}$ |
| | Primary – Flotation | $W_W$ |
| | Primary – Pressure | $P_c$ |
| | Primary – Surge Pressure | $P_c+P_{cs}$ |
| | Secondary – Thermal | Range ($T_{c\,min}$, $T_{c\,max}$) |
| D | Primary – Sidewall Compression | $P_E + P_L$ |
| | Primary – Buckling due to External Pressure | $P_E + P_L + P_{gw}$ |
| | Primary – Flotation | $W_W$ |
| | Primary – Pressure | $P_d$ |
| | Primary – Surge Pressure | $P_d+P_{ds}$ |
| | Secondary – Thermal | Range ($T_{d\,min}$, $T_{d\,max}$) |
| | Secondary – Seismic | $[SSE_W^2 + (SSE_S+SSE_D)^2]^{1/2}$ |

Note: Terms are defined in Section 3.7

## 3.4 Fatigue Evaluation

### 3.4.1 Code Class 3 Piping

Class 3 HDPE piping is evaluated for fatigue due to thermal cycles by following the general requirements in ND-3611.2 of the ASME Code. When applicable, this involves the reduction of HDPE allowable stresses based on the number of full range temperature cycles over the plant design life. EPRI Report 1015062 recommends the use of a "Stress Range Reduction Factor" only when the number of full range temperature cycles over the plant design life exceeds 7000 cycles. As noted in Section 9.5 (and in EPRI Report 1015062), normal operation of buried HDPE piping in Class 3 essential service water piping systems is essentially a steady state condition with little or no temperature variation, therefore fatigue due to temperature cycles will be negligible.

In addition, the stress intensification factors (SIFs) and stress indices ($B_1$ and $B_2$) used in equations for calculating stresses at components are based on fatigue testing of HDPE piping, and are provided in Sections 3.11, 3.12, and 4.6, and therefore indirectly account for fatigue in Class 3 HDPE piping components. No cumulative usage factor is calculated for HDPE Class 3 piping. See Section 9.5 for details on fatigue loading.

## 3.5 Functional Capability

General Design Criterion 2 of 10 CFR Part 50 requires that Class 3 piping systems essential for safe shutdown of the plant remain capable of performing their safety function for Service Level D loading conditions. This criterion is met by meeting the recommendations in NUREG-1367, "Functional Capability of Piping Systems." Table 3-3 summarizes the criteria to be used to ensure that the functional capability requirement of GDC 2 is met.

Table 3-3: Functional Capability of Piping ASME Class 3

| Criteria | Class 3 | |
|---|---|---|
| | Equation | Allowable |
| Wall Thickness | $D_o/t \leq 50$ | Meet |
| Service Level D | Primary – Longitudinal Stress | Requirements of Section 3.11.1 or 0.4 × Material Tensile strength at Yield |
| External Pressure | $P_{external} \leq P_{internal}$ | Meet |

**Notes:**

1. General Note: Applicable to Level D plant events for which the piping system must maintain an adequate fluid flow path.
2. General Note: Applicable to ASME Code Class 3 when the following are met:
   a. Dynamic loads are reversing
   b. Steady-state bending stress from deadweight loads does not exceed: $\frac{B_2 M}{Z} \leq 0.25S$

## 3.6 Material Properties

Piping materials are made from a bimodal pipe grade high density polyethylene material and conform to the requirements specified in Appendix B. Materials will have an ASTM D3350 cell classification of 445574C. Pipe will be manufactured in accordance with Appendix B and ASTM D3035 for sizes below 3" NPS, and ASTM F714 for sizes 3" NPS and larger.

### 3.6.1 Material Designation

The HDPE pipe material designation code identifies the standard classification of essential properties. For this Topical Report one designation is used, PE 4710.

- The first two letters, "PE" designates that the material is a polyethylene piping material.
- The first digit, 4, identifies the resin's density classification in accordance with ASTM D3350. Certain properties, including stress/strain response are dependent on the crystalline content.
- The second digit, 7, identifies the material's standard classification for slow crack growth resistance, also in accordance with ASTM D3350, which relates to the resin's capacity for resisting the initiation and propagation of slowly growing cracks when subjected to localized stress intensification. For PE 4710, the 7 denotes a minimum PENT rating of 500hrs; however, this Topical Report requires a higher PENT rating of at least 2000hrs.
- The third and fourth digit combined, 10, denotes the material's recommended hydrostatic design stress (HDS), for water at 73°F, in units of 100psi. For PE 4710, the 10 represents a HDS of 1000psi, however this Topical Report requires a more conservative (lower) HDS of 800psi.

### 3.6.2 Stress/Strain represented by an Apparent Modulus

The potential range of stress/strain response of a material is bounded by two extremes. At one extreme the response can be perfectly elastic, where the magnitude of the strain is always proportional to the magnitude of the applied stress. At the other extreme, deformation caused by the application of a stress is neither instantaneous nor proportional to the stress. Deformation is delayed and the rate and the final extent of deformation are dependant upon the magnitude and duration of the applied stress. Apparent modulus can also be derived for the condition of compressive stress. Such a value tends to be somewhat larger because the resultant deformation causes a slight increase in the area that resists the applied stress; however, the resultant increase is generally small allowing the tensile stress value to adequately and conservatively represent the compression state.

Even though PE piping materials exhibit visco-elastic behavior, this concept allows for piping design to be conducted by means of the same equations that have been developed based on the assumption of elastic behavior; however, it is important to recognize that a value of an apparent modulus that is used for a design must adequately reflect the visco-elastic response that is expected to occur under the anticipated service conditions. In this regard, it should be noted that a value of apparent modulus is dependent not only on duration of loading, but also on stress intensity. In nearly all PE pipe applications the maximum stresses that are generated by reactions other than that which is caused by internal pressure are of a magnitude that seldom exceeds the range of about 300 to 400psi (Reference 13.1.7).

### 3.6.3 Determination of Working Strength

The working tensile strength of PE is affected by essentially the same variables that affect its stress/strain relationship; principally, magnitude of load, duration of loading, temperature and environment. One important difference is that unlike strain response which is in reaction to the nominal value of applied stress, fracture can result from either the effect of a nominal stress, or from that of a local intensified stress.

In a pressure pipe application, the major nominal stress is that which is induced by internal hydrostatic pressure. Accordingly, standards for pressure rated PE pipe require that each material from which a PE pipe is made have an experimentally established long-term hydrostatic strength (LTHS). The pressure rating of a PE pipe is based on this hydrostatic design basis after it has been reduced to a hydrostatic design stress (HDS) by means of applying a design factor (DF) that gives adequate consideration to the additional nominal and localized stresses that can be generated by other conditions.

### 3.6.4 Compressive Strength

Unlike tensile loading, which can result in a failure if excessive, a compressive loading seldom leads to a fracture. Instead, there is a resultant creep in compression, which causes a thickening of the areas resisting the stress; an effect that tends to reduce the true stress. If the stress is excessive, failure can occur by yielding (excessive deformation) rather than by a fracture process. For these reasons, it is customary to report compressive strength as the stress required to deform a test sample to a certain strain.

### 3.6.5 Other Engineering Properties

A. Mechanical Properties

Poisson's Ratio – Any stretching or compressing of a test specimen in one direction, due to uniaxial force (below the yield point) produces an adjustment in the dimensions perpendicular to the force. A tensile force in the axial direction causes a small contraction in the lateral direction. The ratio of the decrease in lateral strain to the increase in axial strain is called Poisson's ratio ($\nu$).

Impact Strength – The concept of impact strength covers at least two important properties:

1) The magnitude of a suddenly applied energy that causes the initiation and propagation of a crack. This is usually assessed by the results of tests on un-notched or bluntly notched specimens.
2) The magnitude of a suddenly applied energy that causes a crack to rapidly propagate. This is usually assessed by means of very sharply notched specimens.

B. Thermal Properties

Coefficient of Expansion/Contraction - A temperature increase or decrease can induce a corresponding increase or decrease in the length of a pipe, the movement of which is unconstrained. In the case of a constrained pipe, it can induce the development of a longitudinal tensile or a compressive stress. Both these effects must be given adequate consideration for the proper installation, design, and operation of a PE piping system.

Thermal Conductivity - The capacity of PE materials to conduct heat is only about one hundredth of that of steel or copper.

Specific Heat - Over the range of typical working temperatures, the quantity of heat required to produce a unit temperature rise per unit mass of PE pipe material is about 46% of that for water; this capacity is little affected by resin density.

### 3.6.6 Material Classification Properties

Density - The crystalline content of a PE resin is reflected by its density. As noted in Section 3.6.1, the crystalline content exerts a major influence on the properties of a PE resin. Generally, as crystalline content increases so does stiffness (apparent modulus), tensile strength, and softening temperature, however, for a given kind of molecular structure, there is a corresponding decrease in impact strength and in low temperature toughness.

Melt Index - The melt index is a measure of the flowability of PE materials when in the molten state. This property is an accepted index for two important characteristics of a PE piping material: 1) its processability, and 2) the molecular weight of its primary constituent PE resin.

Flexural Modulus - In this test, a specimen is supported at both ends and a load is applied in the center at a specified crosshead rate. The flexural modulus is determined at the point when the strain in the outer fiber reaches a value of 2%. The modulus is the ratio of the stress in the outer fiber that results in the 2% strain.

Tensile Strength at Yield - A tensile test is the traditional means for determining the strength of metals and other materials, by which the stress/strain behavior of the material of interest is evaluated under a constant rate of straining.

Color and UV Stabilization - ASTM D3350 also includes a code denoting the combination of color, (natural, or colored, or black) and ultra violet (UV) stabilizer system that is used in the piping material.

## 3.7 Nomenclature

| | | |
|---|---|---|
| A | = | cross sectional area, $in^2$ |
| B | = | burial factor |
| $B_1$ | = | stress index, Table 3-5 |
| $B_2$ | = | stress index, Table 3-5 |
| $B_d$ | = | trench width, ft |
| c | = | the sum of mechanical allowances and erosion allowance, in |
| D | = | average outside diameter of pipe in accordance with ASTM F714 or D3035, in |
| DR | = | dimension ratio of pipe = average outside diameter of the pipe divided by the minimum fabricated wall thickness = D/ $t_{fab\ min}$ |
| DW | = | dead weight of pipe and contents, lb |
| E′ | = | modulus of soil reaction, psi (Data is site specific) |
| $E'_N$ | = | modulus of soil reaction of native soil around trench, psi ($E'_N$ is site specific) |
| $E_{pipe}$ | = | apparent modulus of elasticity of pipe per Table 3-11, psi |
| $f_o$ | = | ovality correction factor, per Table 3-13 |
| $F_a$ | = | axial force limits due to the specified Design, Service Level A, B, C, or D applied mechanical loads, lb |
| $F_{aC}$ | = | axial force range due to thermal expansion, contraction and/or the restraint of free end displacement, lb |
| $F_{aD}$ | = | axial force due to the non repeated anchor motion, lb |
| $F_{aE}$ | = | axial force range due to the combined effects of seismic wave passage, seismic soil movement, and building seismic anchor motion effects, lb |
| $F_S$ | = | soil support factor, per Table 3-10 |
| g | = | acceleration due to gravity, $ft/s^2$ |
| h | = | flexibility characteristic, (See Section 3.12.2.C) |
| H | = | height of ground cover, ft |
| $H_{gw}$ | = | height of ground water above bottom of pipe, ft |
| i | = | stress intensification factor, per Table 3-8 |
| k | = | longitudinal stress factor per Table 3-6 |
| K | = | bedding factor = 0.1 |
| L | = | deflection lag factor, 1.25 to 1.50, or 1.0 if using the soil prism pressure |
| M | = | resultant moment due to the specified Design, Service Level A, B, C, or D applied mechanical loads, in-lb |

| | | |
|---|---|---|
| $M_C$ | = | resultant moment range due to thermal expansion, contraction and/or the restraint of free end displacement, in-lb |
| $M_D$ | = | resultant moment due to the non repeated anchor motion, in-lb |
| $M_E$ | = | resultant moment range due to the combined effects of seismic wave passage, seismic soil movement, and building seismic anchor motion effects, in-lb |
| $M_{elb}$ | = | the inter curve length of the last heavy wall segment of the mitered elbow that contains the taper shown in Figure 7-2 |
| $M_{fusion}$ | = | the total length of pipe to be able to get two clamps on the elbow in the fusing machine to securely hold the mitered elbow while fusing it to straight pipe. This length includes the miter safe end and the last miter segment that contains the counter-bore. |
| MDF | = | Manufacturer de-rating factors for HDPE fittings |
| P | = | internal piping pressure, including pressure spikes due to transients from anticipated water hammer events, psi |
| $\Delta P$ | = | differential pressure due to negative internal pressure of pipe and miters, psi |
| $P_n$ | = | design or Service Level A, B, C, or D internal pressure, psi specified in the Design Specification |
| $P_{ns}$ | = | Surge pressures for Service Levels B through D, psi |
| $P_D$ | = | internal design pressure at the specified design temperature $T_D$, both specified in the Design Specification, not including consideration of pressure spikes due to transients, psi |
| $P_E$ | = | vertical soil pressure due to earth loads, lb/ft$^2$ |
| $P_{gw}$ | = | pressure due to ground water, lb/ft$^2$ |
| $P_{hydro}$ | = | external hydrostatic pressure, equal to earth plus groundwater pressure plus surcharge load, psi |
| $P_L$ | = | vertical soil pressure due to surcharge loads, lb/ft$^2$ |
| $P_m$ | = | Miter elbow internal design pressure at $T_D$; includes 50% repetitive surge overpressure tolerance, psi |
| R | = | buoyancy reduction factor |
| $R_1$ | = | effective radius of miter bend, defined as the shortest distance from the pipe centerline to the intersection of the planes of adjacent miter joints. |
| $r_2$ | = | elbow mean radius of pipe using nominal wall $t_{elb}$ |
| S | = | allowable stress, also referred to as HDS, (HDS=HDB×DF), (Table 3-4) |
| SDR | = | (Standard Dimension Ratio) a specific ratio of the average specified outside diameter to the minimum specified wall thickness ($D_o/t$) for outside diameter controlled plastic pipe. |
| $S_{comp}$ | = | allowable side wall compression stress per Table 3-12 |
| $SSE_W$ | = | Safe Shutdown Earthquake due to effects of seismic wave passage |
| $SSE_S$ | = | Safe Shutdown Earthquake due to effects of soil movement |
| $SSE_D$ | = | Safe Shutdown Earthquake due to effects of anchor movements |
| T | = | Temperature, °F |
| $\Delta T$ | = | $T_{water} - T_{ground}$, °F |
| $\Delta T_{eq}$ | = | equivalent temperature rise, °F |

| | | |
|---|---|---|
| $T_D$ | = | Design Temperature, °F |
| t | = | nominal pipe wall thickness, in = $t_{fab\ min}$ |
| $t_{design}$ | = | minimum required wall thickness, in |
| $t_{fab\ min}$ | = | minimum fabricated thickness in accordance with ASTM F714 or ASTM D3035, in |
| $t_{flange}$ | = | Flange adapter wall thickness, in |
| $t_{min}$ | = | minimum wall thickness for pressure, in |
| $t_{elb}$ | = | minimum elbow miter pipe wall-thickness (per Design Specification) |
| $T_{ground}$ | = | temperature of soil around pipe, °F |
| $T_{n\ max}$ | = | maximum temperature for Service levels A though D, °F |
| $T_{n\ min}$ | = | minimum temperature for Service levels A though D, °F |
| $T_{water}$ | = | temperature of water running through pipe, °F |
| v | = | maximum flow velocity of water in pipe, ft/s |
| $W_c$ | = | weight of pipe contents (equals 0 when pipe is empty), lb/ft |
| $W_P$ | = | weight of pipe per unit length, lb/ft (exclude weight of contained liquid to represent the worst case of an empty pipe) |
| $W_w$ | = | weight of water displaced by pipe, per unit length, lb/ft |
| Z | = | section modulus of pipe, $in^3$ |
| $\alpha$ | = | coefficient of thermal expansion of pipe, 1/°F |
| $\theta$ | = | elbow angle of miter cut of pipe end (degrees) |
| $\alpha_{elb}$ | = | elbow angle of change-in-direction at miter joint = $2\theta$ |
| $\nu$ | = | Poisson ratio (0.35 for short duration loads (5 min. or less) to 0.45 for long duration loads (greater than 5 min.)) |
| $\Omega$ | = | (ring deflection) change in diameter as a percentage of the original diameter, commonly called the change in ring diameter, calculated in Table 3-9 |
| $\Omega_{max}$ | = | (maximum allowable ring deflection) maximum allowable change in diameter as a percentage of the original diameter, commonly called the maximum change in ring diameter, Table 3-9 |
| $\varepsilon_a$ | = | Strain in the pipe from earthquake wave computer analysis (in/in) |
| $\varepsilon_b$ | = | Bending strain in the buried piping due to wave propagation |
| $\varepsilon_{soil}$ | = | maximum soil strain due to seismic wave passage (in/in) |
| $\rho_{dry}$ | = | density of dry soil, $lb/ft^3$ specified in the Design Specification |
| $\rho_{saturated}$ | = | density of saturated soil, $lb/ft^3$ |
| $\sigma_E$ | = | tensile stress in the pipe due to an earthquake, psi |
| $\sigma_{sw}$ | = | circumferential compressive stress in the sidewalls of the pipe and miters, psi |
| $\sigma_t$ | = | tensile stress in the pipe, psi |

### 3.8 Hydrostatic Design Basis for Temperatures Over 140°F and Up To 160°F

The Plastic Pipe Institute studied the methods for forecasting the effective long term performance of polyethylene piping materials. As a result of the study, the Hydrostatic Stress Board has determined that the three-coefficient Rate Process Method (RPM) equation provides the best correlation between the calculated long-term performance projections and known field performance of several PE piping materials. The RPM is described in ASTM D2837 and Plastic Pipe Institute Technical Note TN-16.

See Section 9.4 for a detailed discussion on elevated temperature design.

### 3.9 Slow Crack Growth Resistance

The average failure time from two test specimens shall meet the minimum requirement shown for each cell classification listed in Table 1- "Primary Properties – Cell Classification Limit" from ASTM D 3350. The cell classification for PE 4710 is PE445574C (this classification exceeds the minimum PE 4710 tensile strength requirement) which requires a minimum PENT test of 500hrs. The PE 4710 material used for safety related systems shall exceed this minimum ASTM value, and shall have a minimum ASTM F1473 PENT test rating of at least 2000hrs (See Appendix B for detailed PE 4710 piping material requirements).

Given the conservative limitations on pipe flaw size specified in Section 10.4.1, this high PE 4710 PENT value ensures Slow Crack Growth brittle failure will not occur during the design life. Section 10.4.1 limits the maximum flaw size to notch depth of 0.125", while a PENT test on a pipe wall thickness of 4.5" is based on a much larger flaw and uses a notch depth of 0.347" (for a 0.787" pipe wall the PENT test would use a notch depth of 0.205".)

The April 2007 Issue 4 of the Journal of Polymer Engineering and Science, pp 477-480, provides an equation for the correlation between PENT and HDPE piping service life. This equation shows that for a given stress intensity (pipe flaw) piping service life is directly proportional to the PENT value. As noted in Jana Laboratories Technical Report "Long-Term Performance of PE Piping Materials in Potable Water Applications," dated 9/17/2009, and listed in the PPI listing of "Municipal / Industrial Publications," accelerated laboratory testing per ASTM F2263 found that PE3408 pipe will have a potable water design life well beyond 100 years. This finding was for an older unimodal HDPE resin that had a minimum PENT value of 100 hours.

The minimum PENT value of 2000 hours noted above is 20 times larger, and based on the above correlation between design life and PENT would indicate a 20 times longer design life of 2000 years.

### 3.10 Pressure Design of Pipe

As explained in Section 9.1, Table 3-4 allowable stresses, S, are based on a DF of 0.5. The design for temperatures above 140°F is described in Section 9.4.

#### 3.10.1 Minimum Required Wall Thickness

The internal pressure design thickness of straight sections of pipe is determined by the following equation:

$$t_{design} = t_{\min} + c$$

$$t_{\min} = \frac{P_D D_O}{2S + P_D}$$

3.10.2 Maximum Required Dimension Ratio

The following maximum required dimension ratio equations are equivalent to, (and are derived from) the minimum wall thickness equation above; and provide a more direct and efficient method for sizing HDPE pipe to roughly match the ID of a steel pipe.

These equations are derived from the Minimum Wall Thickness equation by dividing both sides of the equation by "t", substituting DR for the resultant D/t term, and then rearranging terms to solve for DR. The IDR equation is derived by substituting ($D_i$ + 2t) for D before dividing both sides of the equation by "t."

The internal pressure maximum required dimension ratio of straight sections of pipe is determined by the following:

$$DR = \frac{D_o}{t}$$

$$IDR = \frac{D_i}{t}$$

$$DR = IDR + 2, (D_o = D_i + 2t)$$

$$DR_{\max} = \frac{2S}{P_D} + 1$$

$$IDR_{\max} = \frac{2S}{P_D} - 1$$

The dimension ratio is an equivalent indirect representation of the pipe wall thickness, and is used with HDPE, since HDPE pipe has standard pipe walls specified by dimension ratios (DR or IDR).

When HDPE pipe interfaces with steel pipe, the HDPE pipe will have a much thicker pipe wall for the same design conditions, therefore, the interfacing HDPE pipe will be sized to roughly match the ID of the steel pipe, and the above $IDR_{max}$ equation will be used to select a pipe wall thickness.

The $IDR_{max}$ will be used to select a pipe wall with a Standard IDR that is equal to or less than the calculated $IDR_{max}$ (the lower the IDR the thicker the pipe wall). As explained in Section 9.0, no corrosion allowance will be used in selecting the HDPE pipe wall. The equivalent DR (DR = IDR + 2) is specified when ordering OD controlled HDPE pipe.

### 3.10.3 Range of Pipe Sizes and Design Conditions

This TR is applicable to buried water system piping with a Design Pressure and Design Temperature up to 200psig and 140°F, respectively, with a possible transient temperature excursion up to 160°F for a period of 30 days for a projected life of 60 years. Approval for HDPE piping identified herein is requested for a period of 40 years. This 40 year time frame is selected to be consistent with the license term of the COL applicants. Straight pipe wall thickness ranges from a minimum standard wall of DR17 to a maximum standard wall of either DR6 or a thickness of 4.5 inches, whichever is thinner, and shall be calculated utilizing a DF of 0.5.

Table 3-4: Allowable Stress, S, for Long-Term Hydrostatic Pressure, psi

| Temperature | Allowable Design Stress | Temperature | Allowable Design Stress |
|---|---|---|---|
| °F | DF = 0.5 | °F | DF = 0.5 |
| ≤73 | 800 | 107 | 638.9 |
| 74 | 794.97 | 108 | 634.45 |
| 75 | 789.96 | 109 | 630.02 |
| 76 | 784.96 | 110 | 625.6 |
| 77 | 779.99 | 111 | 621.2 |
| 78 | 775.03 | 112 | 616.82 |
| 79 | 770.09 | 113 | 612.45 |
| 80 | 765.17 | 114 | 608.1 |
| 81 | 760.27 | 115 | 603.76 |
| 82 | 755.39 | 116 | 599.44 |
| 83 | 750.52 | 117 | 595.13 |
| 84 | 745.67 | 118 | 590.83 |
| 85 | 740.84 | 119 | 586.56 |
| 86 | 736.03 | 120 | 582.29 |
| 87 | 731.24 | 121 | 578.04 |
| 88 | 726.46 | 122 | 573.81 |
| 89 | 721.7 | 123 | 569.59 |
| 90 | 716.96 | 124 | 565.38 |
| 91 | 712.23 | 125 | 561.19 |
| 92 | 707.52 | 126 | 557.01 |
| 93 | 702.83 | 127 | 552.85 |
| 94 | 698.16 | 128 | 548.7 |
| 95 | 693.5 | 129 | 544.57 |
| 96 | 688.86 | 130 | 540.45 |
| 97 | 684.24 | 131 | 536.34 |
| 98 | 679.63 | 132 | 532.25 |
| 99 | 675.04 | 133 | 528.17 |
| 100 | 670.46 | 134 | 524.11 |
| 101 | 665.91 | 135 | 520.05 |
| 102 | 661.36 | 136 | 516.02 |
| 103 | 656.84 | 137 | 511.99 |
| 104 | 652.33 | 138 | 507.98 |
| 105 | 647.84 | 139 | 503.98 |
| 106 | 643.36 | 140 | 500 |

*See Section 9.1 for a discussion on how these values are used for a 60 year Design Life

3.10.4 Allowable Service Level Spikes due to Transient Pressure Surges

The sum of the maximum anticipated operating pressure plus the maximum anticipated Level B, C, and D pressure spikes due to transient pressure surges (water hammers) shall be no greater than 1.5 times the piping system Design Pressure, $P_D$.

3.10.5 Limits on Sustained Pressure ($P_a$).

The maximum service level A, B, C or D sustained pressure ($P_a$) shall not exceed the Design Pressure ($P_D$).

3.10.6 Pressure Design of Butt Fusion Joints and Flanges

A. Polyethylene pipe shall be joined using the butt fusion process. All connections to metallic piping shall be flanged joints.

B. HDPE flange adapters shall comply with the specifications, standards, and requirements listed in Section 2.0 and Appendix B. The flange adapter fabricator shall ensure the pressure rating of the flange adapter based on a design factor (DF) of 0.5 is greater than or equal to the Design Pressure ($P_D$) of the attached straight pipe.

C. The PE flanged joint assembly shall include a flange adapter with metallic backing ring, which together, shall provide a leak tight joint up to and including the piping hydrostatic test pressure. In addition, the maximum transient pressures per Section 3.10.4 shall not cause permanent deformation of the pipe.

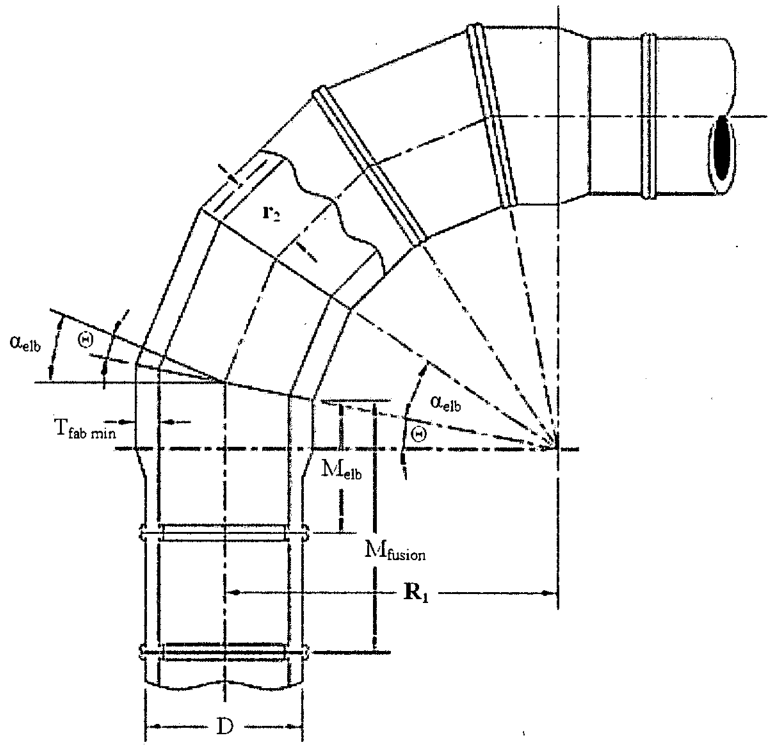
D. The Flange Adaptor hub thickness ($t_{hub}$) is a minimum of 1.25 times the nominal neck (pipe-wall) thickness (t) (i.e., $t_{hub} = 1.25t$). The Flange Adapter is either molded or machined from extruded pipe material. The neck length is sufficiently long for butt fusion joining when clamped in one "jaw" of the fusion machine.

3.10.7 Pressure Design of Mitered Elbows

A. The pressure rating of the mitered elbow, $P_m$, is calculated as the lesser of the two equations in Section 3.10.8, calculated for a wall thickness per Section 3.10.7.B below. The design pressure rating $P_m$ is greater than or equal to $P_D$.

B. The minimum fabricated wall thickness of the reinforced sections of the mitered elbow is equal to at least 1.22 times the minimum fabricated wall thickness of the attached straight pipe. This minimum fabricated wall thickness shall not be less than a wall thickness of DR 13.5. The additional wall thickness is provided by enlarging the pipe OD while maintaining the pipeline ID.

Figure 3-1: Nomenclature for Mitered Elbows, Constant ID, 5-Segment, Reinforced, 90 Degree Elbow




C. Mitered joints of 3° or less (angle $a_{elb}$ in Figure 3-1) do not require re-design consideration as mitered elbows. The required method for pressure design of mitered elbows is given in Section 3.10.8.

D. Mitered elbows shall comply with the requirements of ND-3644 of the ASME Code with the following exceptions: ND-3644(a) wall thickness is determined as outlined in Section 3.10.7.A and B above, ND-3644(a), and ND-3644(e) full penetration welds are replaced with butt fusion joints. Heavier wall segments with larger outside diameter will be used for elbow fabrication to minimize flow restriction. Ninety degree, 45°, and 22.5° elbows are permitted. Elbows less than 90° may have three or fewer mitered joints.

3.10.8 Mitered Elbows

A. The maximum allowable internal pressure is the lesser value calculated from equations below.

$$P_m = \frac{St_{elbow}}{r_2}\left(\frac{t_{elbow}}{t_{elbow} + 0.643\tan\theta\sqrt{t_{elbow}r_2}}\right)$$

or

$$P_m = \frac{St_{elbow}}{r_2}\left(\frac{R_1 - r_2}{R_1 - 0.5r_2}\right)$$

B. The miter cut, $a_{elb}$, is less than or equal to 22.5° + 3°.

C. The angle of miter cut of pipe end shall not vary more than 3° in any direction on a mitered elbow.

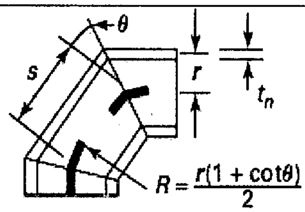
## 3.11 Longitudinal Stress Design

### 3.11.1 Longitudinal Applied Mechanical Loads

Longitudinal stresses due to axial forces and bending moments resulting from applied mechanical loads shall not exceed k×S where,

$$B_1 \frac{P_a D}{2t} + 2B_1 \frac{F_a}{A} + B_2 \frac{M}{Z} \leq k \times S$$

Table 3-5: Stress Indices, $B_1$ and $B_2$

| Description | Primary Stress Index | | Sketch |
|---|---|---|---|
| | $B_1$ | $B_2$ | |
| Straight Pipe | 0.5 | 1.0 | -- |
| Fused Joint | 0.5 | 1.0 | -- |
| Mitered Elbow | $0.5 \times MDF$ | $0.75 \times i \times MDF$ See Table 3-8 for $i$ |  |



| Fitting Type | Derating, MDF[1] |
|---|---|
| Fabricated 90° Elbow – 5 Segment | 1.25 |
| Fabricated 45° Elbow – 3 Segment | 1.25 |
| Fabricated 45° Elbow – 2 Segment | 1.38 |
| Fabricated 22.5° Elbow – 5 Segment | 1.25 |

1. Reference 13.7.1, EPRI Report 1013549, Nondestructive Evaluation: Seismic Design Criteria for Polyethylene Pipe Replacement Code Case

Table 3-6: Design and Service Level Longitudinal Stress Factors

| Service Level | Design | A | B | C | D |
|---|---|---|---|---|---|
| *k*-Factor | 1.0 | 1.0 | 1.1 | 1.33 | 1.33 |

3.11.2 Short Duration Longitudinal Applied Mechanical Loads

For the assessment of short duration loads (less than five minutes), the allowable stress, S, is replaced by one of the two following alternatives,

A. 40% of the tensile strength at material yield, or

B. The values in Table 3-7.

Table 3-7: Short Duration (≤ 5 minutes) Allowable Longitudinal Tensile Stress Values

| Temp, °F | ≤ 70 | 100 | 120 | 140 | 176 |
|---|---|---|---|---|---|
| S, psi | 1200 | 940 | 770 | 630 | 400 |

3.12 Temperature Design

3.12.1 Minimum Temperature

The PE material brittleness temperature shall not be warmer than -88°F when tested in accordance with ASTM D746 as required by ASTM D3350. System design temperatures shall not be less than 20°F.

3.12.2 Design for Expansion and Contraction

A. Fully Constrained Thermal Contraction

The stress resulting from the assumption of fully constrained thermal contraction of the buried pipe when $T_{water} < T_{ground}$, increased by the tensile stress due to axial contraction from Poisson effect, shall not exceed the allowable stress $S$.

$$\sigma_{\tau} = \left| E_{pipe} \times \alpha \times \Delta T - \nu \times \frac{P \times D}{2t} \right| \leq S$$

For fully constrained thermal expansion and contraction evaluations the calculated thermal stresses are based on the temperature differential between the pipe operating temperature and the soil temperature.

B. Fully Constrained Thermal Expansion

The tensile stress resulting from the assumption of fully constrained thermal expansion of the buried pipe when $T_{water} > T_{ground}$, shall not exceed the allowable stress $S$.

$$\sigma_{\tau} = E_{pipe} \times \alpha \times \Delta T \leq S$$

C. Alternative Thermal Expansion or Contraction Evaluation

As an alternative to the above equations, the soil stiffness may be accounted for to calculate pipe expansion and contraction stresses. If the alternate thermal expansion and contraction evaluation is performed in the final analysis, the range of moments for the expansion and contraction cases will be evaluated instead of evaluating the expansion and contraction cases. The stresses shall satisfy the following equation:

$$\frac{iM_C}{Z} + \frac{F_{aC}}{A} \leq 1100\,psi$$

Table 3-8: Stress Intensification Factors, *i*

| Fitting or Joint | *i* |
|---|---|
| Straight Pipe | 1.0 |
| Butt Fusion | 1.0 |
| Mitered Elbow | 2.2[1] |
| Flange | 1.0 |

Note 1: See Reference 13.7.4

A property that distinguishes PE pipe from metallic pipe is that its linear coefficient of thermal expansion is about ten times larger. This means a larger thermal expansion/contraction in the case of unconstrained pipe. Another distinguishing property is a much lower apparent modulus of elasticity. In the case of constrained buried pipe, this leads to a much lower value of thermally induced longitudinal stresses.

Due to its relatively high thermal expansion coefficient and poor thermal conductivity, a small thermal gradient in the radial direction will exist in the thick wall of an HDPE pipe.

A Finite Element Analysis (FEA) model of a portion of the largest HDPE pipe will be performed and any internal moments created by the radial thermal gradient stresses are added to the alternative thermal expansion equation to demonstrate that the thermal gradient stresses across the pipe wall are acceptable.

A minimum 3 feet of soil cover is provided over the top of piping for freeze protection. Soil is a poor conductor of heat, and it serves to insulate the pipe from low ambient temperatures. This insulating property of soil also serves to minimize the temperature gradient (and reduce thermal stresses) through the HDPE pipe wall of hot water pipes (115°F to 140°F water temperatures), as there is a significant temperature gradient through the backfill surrounding the pipe.

For very thick pipe walls, the surface temperature at the OD of a hot HDPE pipe is estimated to be 80°F to 90°F (not the lower 60°F associated with cold water pipes), and the surface temperature is even higher for thinner wall hot pipes. When operating with 115°F water the radial temperature gradient for a thick wall pipe is 25°F to 35°F (not 55°F for a 60°F surface temperature). This shows that a buried pipe's higher surface temperature will reduces its radial temperature gradient and the associated radial stress.

## 3.13 Non-repeated Anchor Movements

The effects of any single non-repeated anchor movements shall meet the following equation:

$$\frac{iM_D}{Z} + \frac{F_{aD}}{A} \leq 2S$$

## 3.14 Soil and Surcharge Loads

### 3.14.1 Ring Deflection

The soil and surcharge loads on a buried HDPE piping system shall not cause a change in pipe outside diameter as a percentage of the average outside diameter, D, beyond a limit $\Omega_{max}$, where:

$$\Omega = \frac{1}{144} \times \frac{K \times L \times P_E + K \times P_L}{\frac{2E_{Pipe}}{3} \times \left(\frac{1}{DR-1}\right)^3 + 0.061 \times F_S \times E'} \leq \Omega_{max}$$

$E_{pipe}$ is per Table 3-11 based on the system design life and

$$P_E = \rho_{saturated} \times H_W + \rho_{dry} \times (H - H_W)$$

Table 3-9: Maximum Allowable Ring Deflection PE

| *DR* | *$\Omega_{max}$(%)* |
|---|---|
| 17.0 | 6.0 |
| 15.5 | 6.0 |
| 13.5 | 6.0 |
| 11 | 5.0 |
| 9 | 4.0 |
| 7.3 | 3.0 |
| 6.0 | 1.5 |

Table 3-10: Soil Support Factor, $F_S$

| | *$B_d$/D, ft/in* | | | | | |
|---|---|---|---|---|---|---|
| E'$_N$/E' | 1.5 | 2.0 | 2.5 | 3.0 | 4.0 | 5.0 |
| 0.1 | 0.15 | 0.30 | 0.60 | 0.80 | 0.90 | 1.00 |
| 0.2 | 0.30 | 0.45 | 0.70 | 0.85 | 0.92 | 1.00 |
| 0.4 | 0.50 | 0.60 | 0.80 | 0.90 | 0.95 | 1.00 |
| 0.6 | 0.70 | 0.80 | 0.90 | 0.95 | 1.00 | 1.00 |
| 0.8 | 0.85 | 0.90 | 0.95 | 0.98 | 1.00 | 1.00 |
| 1.0 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1.5 | 1.30 | 1.15 | 1.10 | 1.05 | 1.00 | 1.00 |
| 2.0 | 1.50 | 1.30 | 1.15 | 1.10 | 1.05 | 1.00 |
| 3.0 | 1.75 | 1.45 | 1.30 | 1.20 | 1.08 | 1.00 |
| 5.0 | 2.00 | 1.60 | 1.40 | 1.25 | 1.10 | 1.00 |

Table 3-11: Modulus of Elasticity of PE Pipe, $E$

(Reference 13.1.7, PPI Handbook on Polyethylene Piping)

| Sustained Temp, °F | PE 4710 Apparent Elastic Modulus, ksi | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sustained Load Duration, hours | | | | | | Duration, years | | | |
| | 0.5 | 1 | 10 | 24 | 100 | 1000 | 1 | 10 | 50 | 100 |
| 73 | 82.0 | 78.0 | 65.0 | 60.0 | 55.0 | 46.0 | 40.0 | 34.0 | 29.0 | 28.0 |
| 80 | 76.26 | 72.54 | 60.45 | 55.80 | 51.15 | 42.78 | 37.20 | 31.62 | 26.97 | 26.04 |
| 90 | 67.24 | 63.96 | 53.30 | 49.20 | 45.10 | 37.72 | 32.80 | 27.88 | 23.78 | 22.96 |
| 100 | 59.86 | 56.94 | 47.45 | 43.80 | 40.15 | 33.58 | 29.20 | 24.82 | 21.17 | 20.44 |
| 110 | 52.48 | 49.92 | 41.60 | 38.40 | 35.20 | 29.44 | 25.60 | 21.76 | 18.56 | 17.92 |
| 120 | 47.56 | 45.24 | 37.70 | 34.80 | 31.90 | 26.68 | 23.20 | 19.72 | 16.82 | 16.24 |
| 130 | 41.00 | 39.00 | 32.50 | 30.00 | 27.50 | 23.00 | 20.00 | 17.00 | 14.50 | 14.00 |
| 140 | 35.26 | 33.54 | 27.95 | 25.80 | 23.65 | 19.78 | 17.20 | 14.62 | 12.47 | 12.04 |
| 176 | 18.0 | 17.2 | 14.3 | 13.2 | 12.1 | 10.1 | 8.8 | -- | -- | -- |

### 3.14.2 Compression of Sidewalls

The circumferential compressive stress in the sidewalls and miters $\sigma_{SW}$ due to soil and surcharge loads (See Section 3.14) shall not exceed $S_{comp}$.

$$\sigma_{sw} = \frac{(P_E + P_L) \times DR}{2 \times 144} \leq S_{comp}$$

Table 3-12: Allowable Circumferential Compressive Stress Capacity Values, $S_{comp}$

| Temp °F | psi |
|---|---|
| 50 | 1180 |
| 73 | 1015 |
| 140 | 520 |
| 160 | 400 |
| 180 | 325 |

### 3.14.3 External Pressure

A. Buckling Due to External Pressure

External pressure from ground water, earth loads, and surcharge loads on a buried PE piping system shall not cause the piping system to buckle.

$$P_{Hydro} = \frac{P_E + P_L + P_{gw}}{144} \leq 2.8\sqrt{\frac{R \times B' \times E' \times E_{pipe}}{12(DR-1)^3}}$$

and the buoyancy reduction and burial factors are:

$$R = 1 - 0.33 \times \frac{H_{gw}}{H}$$

$$B' = \frac{1}{1 + 4 \times e^{(-0.065 \times H)}}$$

B. Effects of Negative Internal Pressure

When the pipe is subject to a negative internal pressure, it shall withstand the differential pressure without credit for the surrounding soil.

$$\Delta P \le \frac{f_0}{2} \times \frac{2E_{pipe}}{1-v^2} \times \left(\frac{1}{DR-1}\right)^3$$

Table 3-13: Ovality Correction Factor, $f_o$

| Percent-Ovality | Ovality Correction Factor |
|---|---|
| 1% | 0.91 |
| 2% | 0.84 |
| 3% | 0.76 |
| 5% | 0.64 |
| 6% | 0.52 |

3.14.4 Flotation

Buried PE piping system shall have sufficient cover to prevent flotation by groundwater. For the U.S. EPR™ to be built by UniStar Nuclear Energy or its partners, the piping will be buried with no anchors. The upward resultant force due to buoyancy on a buried pipe in saturated soil is:

$$W_W < W_P + P_E \times \frac{D}{12}$$

3.14.5 Surface Loads (AASHTO Vehicle Loading)

3.14.6 Vehicular loads are based on the American Association of State Highway and Transportation Officials standard truck loads. For calculating the soil pressure on the PE pipe, the loading is assumed to be an H-20 (HS-20) truck with a total weight of 40,000lbs. The weight is distributed with 8,000lbs on the front axle and 32,000lbs on the rear axle. The HS-20 has the same axle loadings as the H-20, but the HS-20 has two rear axles. For these trucks, the maximum wheel load is found at the rear axle(s) and equals 40% of the total weight of the truck. The maximum wheel load is used to represent the static load applied by either single or double axles.

A. Impact factor

Impact load is determined by multiplying the static wheel load by an impact factor. Table 3-14 gives impact factors for vehicles on paved roads. For unpaved roads, impact factors of 2.0 or higher may occur, depending on road surface.

Table 3-14: Typical Impact Factors for Paved Roads

| Cover Depth, ft | Impact Factor, $I_f$ |
|---|---|
| 2.0 < H < 3.0 | 1.50 |
| 3.0 < H < 4.0 | 1.40 |
| 4.0 < H < 5.0 | 1.30 |
| 5.0 < H < 6.0 | 1.20 |
| 6.0 < H < 7.0 | 1.10 |
| H > 7.0 | 1.0 |

*AWWA PE Pipe Design and Installation-2006

Pavement reduces the live load pressure reaching a pipe. A stiff, rigid pavement spreads the load out over a large area significantly reducing the vertical soil pressure. Table 3-15 gives the vertical soil pressure underneath an H-20 (HS-20), truck traveling on a paved highway (12-inch thick concrete). An impact factor is incorporated. For use with heavier trucks, the pressures can be adjusted proportionally to the increased weight as long as the truck has the same tire area.

Table 3-15: Soil Pressure under H-20 Load (12" thick)

| Depth of Cover, ft | Soil Pressure, lb/ft$^2$ |
|---|---|
| 1.5 | 1400 |
| 2 | 800 |
| 3 | 600 |
| 4 | 400 |
| 5 | 250 |
| 6 | 200 |
| 7 | 175 |
| 8 | 100 |
| > 8 | Negligible |

Flexible pavements (or unpaved surfaces) do not have the bridging ability of pavement and, thus transmit more pressure through the soil to the pipe than given by Table 3-15. The maximum pressure may occur directly under the wheels of one vehicle or somewhere in between the wheels. The following table gives the largest of the maximum pressure for two passing H-20 trucks on an unpaved surface.

Table 3-16: Soil Pressure under H-20 Load (unpaved or flexible pavement)

| Depth of Cover, ft | Soil Pressure, lb/ft$^2$ |
|---|---|
| 1.5 | 2000 |
| 2 | 1370 |
| 2.5 | 1000 |
| 3 | 780 |
| 3.5 | 620 |
| 4 | 520 |
| 6 | 290 |
| 8 | 190 |
| 10 | 120 |
| > 10 | Negligible |

Railroad Loads

The live loading configuration used for pipes under railroad is the Copper E-80 loading, which is an 80,000lb load that is uniformly applied over a 3′ x 8′ area on 5ft centers. The area represents the 8ft width of and the spacing between locomotive drive wheels. Live loads are based on the axle weight exerted on the track by two locomotives and their tenders coupled together in double header fashion.

Table 3-17: Live Load Pressure for E-80 Railroad Loading

| Depth of Cover, ft | Soil Pressure, lb/ft$^2$ |
|---|---|
| 2.5 | 2780 |
| 3.0 | 2650 |
| 4.0 | 2420 |
| 5.0 | 2175 |
| 6.0 | 1930 |
| 7.0 | 1720 |
| 8.0 | 1530 |
| 9.0 | 1368 |
| 10.0 | 1209.6 |
| 20.0 | 475.2 |

Live loads such as those imposed by trucks, rail, and construction equipment or other construction conditions will be considered in the analysis and design. The pressure transmitted to the buried pipe under these loads is computed as follows:

$$P_p = 0.48 \frac{P_s}{H^2\left[1+\left(\frac{d}{H}\right)^2\right]^{2.5}}$$

Where

$P_p$ = surface load transmitted to the buried pipe, psi
d = offset distance from the surface load to buried pipe, in.
H = thickness of soil cover above the pipe, in.
$P_s$ = concentrated surface load, lbs.

The magnitude of $P_P$ above is multiplied by an impact factor. The magnitude of $P_P$ may be taken from Tables 3-14, 3-15, and 3-16 which is based on AASHTO HS-20 Truck and Copper E-80 railroad loads.

## 3.15 Seismic Design – Seismic Induced Stresses

Seismic-induced damage to buried pipe is largely due to wave propagation or permanent ground deformation resulting from landslides, fault movement, and liquefaction-induced lateral spread. Seismic anchor movements are taken into account where the piping enters a building or structure. For the case of piping anchored to an adjacent building, strain development due to settlement of the building should be evaluated. The seismic effects on buried piping are self limiting in that strains are limited by the surrounding soil. Therefore, the stresses due to these strains are secondary in nature.

The stresses in the buried PE piping system due to soil strains caused by seismic wave passage and building seismic anchor motion effects are evaluated. The stresses shall satisfy the following equation:

$$\frac{iM_E}{Z} + \frac{F_{aE}}{A} \leq 1100 psi$$

Seismic wave passage, seismic soil movement, and building seismic anchor motion loads are combined by square root sum of the squares. Section 4.1.2 provides a method for the analysis of seismic wave passage, seismic soil movement, and building seismic anchor motion effects.

## 3.16 Flange Joint Evaluation

PE to steel flanged joints are used. The maximum sustained pressure that the flange joint can be subjected to is a 320psig hydro test pressure (for a 200psig design pressure). The flange joint shall also be designed to accommodate the transient surge pressures specified in Section 3.10.4.

### 3.16.1 HDPE to Steel Flanges

The PE to steel flanges are demonstrated to have adequate capacity if the requirements of Section 3.10.6 are met for the flange connection, and the requirements of Section 8.6 are met at the fusion joint connecting the PE pipe to the PE flange adapter, and the flange joint is installed in accordance with the requirements of Section 7.5.2:

A. The flange bolt torque requirements specified in Section 7.5.2.F is met.

B. Material for the flange joint bolting shall be carbon steel SA-307 Grade B, as listed in ASME Section II, Part D, Subpart 1, Table 3, for Section III, Class 3 piping bolting materials.

C. Steel flanges are Class 150 flat faced flanges conforming to the requirements of ASME Section III and ASME B16.5 or B16.47 as applicable.

# 4.0 PIPING ANALYSIS METHODS

## 4.1 Seismic Analysis Input for Buried Piping

There are two potential sources for seismic loads on the piping: loads from wave propagation in the soil and from seismic anchor motion (SAM) of the anchor that forms the boundary for the buried pipe. Sections 4.1.1 and 4.1.2 present the methodology for calculating the loads from these sources. Because the loads and stresses from these two sources are independent, they are calculated separately and combined using the square root sum of the squares (SRSS) method.

### 4.1.1 Seismic Anchor Movements

The effects of differential displacements of structures, greater than 1/16", to which the piping system attaches during an SSE are considered. The maximum relative displacement for each anchor location is obtained from the results of the structural analysis for the supporting structure or calculated from the applicable floor response. These movements will be applied to the short run of metal piping from the building to the connection to the HDPE pipe. While these movements are not directly loading the HDPE pipe, there is still some effect on the HDPE pipe from these building movements.

If the relative displacement between locations is small (less than 1/16") the anchor movement will not be required for the stress analysis.

The analysis of these seismic anchor motions (SAMs) will be performed as a static analysis. The results of this analysis are combined with the piping system seismic inertia analysis results by absolute summation when an enveloped uniform support motion is used for the dynamic analysis, per Standard Review Plan (NUREG-0800) Section 3.7.3.

The anchor location cannot be located directly at the HDPE/steel flange, and must be located on the adjacent steel piping. This portion of piping will be unburied. The combined anchor design loads are determined in the above ground piping analysis using traditional pipe stress analysis software. To determine the anchor loads, a computer model is used for the unburied portion of metallic piping and the model will include the weight of the metallic piping from the anchor point to the HDPE/steel interface flange. The model will also include a lumped mass at the end of the metallic piping that bounds the total weight of the HDPE flange, steel transition flange and metallic backing ring.

### 4.1.2 Analysis for the Effects of Seismic Wave Passage Through Soil

The buried pipe will be qualified by analysis for the effects of seismic wave passage as follows:

Step 1: The strains from seismic wave passage, and seismically-induced permanent or temporary movements are obtained by a site-specific geotechnical/civil investigation.

Step 2: The soil strains are converted into an equivalent temperature rise of the buried pipe, as follows:

$$\Delta T_{eq} = \frac{\varepsilon_{soil}}{\alpha}$$

Step 3: The pipe-soil system is modeled as a piping system constrained by soil springs.

(a) The pipe model will consider two cases: short-term modulus (<10 hours, Table 3-11) for wave passage and long-term modulus for permanent soil movement (permanent seismic anchor motion).

(b) The soil model will have at least a bi-linear stiffness, and shall consider two cases: upper and lower bound of soil stiffness.

Refer to ASCE, Guidelines for the Seismic Design of Oil and Gas Pipeline Systems, 1984, and ASCE 4 Seismic Analysis of Safety-Related Nuclear Structures and Commentary, or American Lifelines Alliance, Guidelines for the Design of Buried Steel Pipes, July 2001,with February 2005 addendum.

Step 4: The equivalent rise of temperature, $\Delta T_{eq}$ is applied to the pipe-soil model to obtain forces and moments throughout the system.

Step 5: The anticipated building seismic anchor movements are applied to the pipe-soil model to obtain forces and moments throughout the system.

Step 6: The anticipated seismic movements are applied to the pipe-soil model to obtain forces and moments throughout the system.

Step 7: The results of Steps 4, 5, and 6 are combined by Square Root Sum of Squares (SRSS), at each point along the piping system to obtain resultant forces and moments.

Step 8: The resultant forces and moments are evaluated as follows:

(a) The axial stresses in pipe, fittings and fused joints shall comply with the requirements of Section 3.11.

(b) Alternatively, the seismic induced strain is determined as follows

$$(\varepsilon_a)_{Earthquake} = \frac{|\sigma_E| + \left|\nu\left(\frac{PD}{2t}\right)\right|}{E}$$

This strain, $(\varepsilon_a)_{Earthquake}$ is limited to the values listed in Table 4-1, where k, the design and Service Level longitudinal stress factors, is defined in Table 3-6.

Table 4-1: Seismic Strain Limits

| *DR* | Allowable Strain |
|---|---|
| $DR \leq 13.5$ | 0.025 × K |
| $13.5 < DR \leq 21$ | 0.020 × K |
| $DR > 21$ | 0.017 × K |

4.2 Response Spectrum Seismic Analysis Method for the Combined System.

For the portion of unburied HDPE piping in a yard vault or in the building, the effects of the ground motion during an SSE event that are transmitted through structures and soil to the piping systems at anchorage locations, is considered. The response spectrum method of analysis, peak values of response are determined for each mode of the piping system by application of floor response spectra, which represent the maximum acceleration response of an idealized single-degree-of-freedom damped oscillator as a function of natural frequency to the vibratory input motion of the structure. If the stresses due to seismic loads can be evaluated and shown to be small, it may be excluded from the analysis: however, if the loads in the unburied portion of HDPE pipe are significant, the stresses in the unburied portion of HDPE pipe are evaluated as follows:

The seismic analysis for a combined system (Steel and HDPE) is conducted as follows:

A. For the non-buried piping, Multiple Input Response Spectra Modal analysis is conducted for the SSE case. The seismic response spectrum is input for the above ground piping and null spectra (a spectra with zero spectral acceleration) is input for the buried pipe. The piping software shall then obtain the interactions between the unburied steel portion of pipe and buried portion of the piping. The intermodal and interspatial combinations are combined by the square root sum of the squares (SRSS). Inter-group combinations are combined using the SRSS. The combination of the equivalent seismic (thermal) and response spectrum (with null spectrum) analysis will be combined using SRSS.

B. For the buried pipe, an equivalent $\Delta T_{eq}$ is calculated per Section 4.1.2. This $\Delta T_{eq}$ is then applied to the buried piping section only.

C. The results from A) and B) above are summed by the SRSS to obtain the total seismic response of a combined system.

## 4.3 Analysis Inputs

### 4.3.1 Design Loads

Bounding Design temperature and pressure values are used as input to the calculations.

Table 4-2: Bounding Design Conditions

| | |
|---|---|
| Design Pressure | up to 200psig |
| Design Temperature | up to 140°F* |

* Including a temperature excursion up to 160°F for 30 days.

### 4.3.2 Pipe Properties

Outside Pipe Diameter, OD, thickness and weight values for HDPE pipe are taken from standard piping catalogs. The following pipe properties are used and documented in the piping analysis:

1. Nominal Size
2. Material
3. Schedule
4. Outside Diameter, OD, in.
5. Wall thickness, in
6. Contents, (water)
7. Weight of contents, lb/ft
8. Weight of pipe, lb/ft

## 4.4 HDPE to Steel Interface

The HDPE flange interface shall have the option to be located in a yard vault or inside the building. If the yard option is selected, the steel piping shall utilize an embedment penetration for the steel piping; this will serve as an anchor and a boundary for the piping analysis. The anchor point in the building or in a vault is designed to stop all forces and moments. The HDPE pipe, at a minimum must contain a seal to prevent ground water from entering the vault or the building. The length of unburied HDPE pipe is minimized, as reasonably achievable, to minimize the stresses due to seismic inertia.

All transitions from steel pipe to PE pipe require a flanged connection. On the metal portion of piping, an ASME B16.5 or ASME B16.47 flange must be welded to the pipe. On the PE portion of the transition, a lap joint type flange adapter is fused to the plastic pipe. A special steel backing flange will be used on the back of the PE flange adapter and must conform to the same ASME B16.5 or ASME B16.47 pattern as the welded steel flange. The stress intensification factors are listed in Table 3-8.

## 4.5 Modeling of PE Elbows

PE elbows include 30°, 45°, and 90° elbows, modeled as mitered bends. The 30° bend consists of two segments, the 45° bend consists of three segments, and the 90° bend consists of five segments. The maximum miter angle is 22.5°. The segment lengths for the 30° bend and the 45° bend are comprised of equal segment lengths. See Figure 3-1(a) & (b) for a sketch which shows how the segments are divided for a 90° bend:

## 4.6 Stress Intensification Factors (SIFs)

Many computer programs automatically calculate SIFs and stress indices based on the ASME Code, which is coded into the software. The buried PE piping evaluation criteria is not programmed into any currently available software. The calculations for the buried PE piping can be done by performing a manual calculation or performing a manual calculation using data extracted from the computer software. The Stress Intensification Factors and stress indices can be input into most pipe stress programs, and are taken from Table 3-5 and Table 3-8.

## 4.7 Soil Springs

The buried section of the piping is subject to loads from earthquakes, temperature differential, and surrounding soil. Details on how the soil springs are calculated are provided in Section 5.4.2. Spring stiffness is based on the local coordinate system of the pipe in the axial, vertical, and transverse directions. These springs must be spaced along the piping at an appropriate spacing. The spacing must be dense enough to model the behavior of the piping while keeping the model to a manageable size. Unlike flexible above ground piping, most of the movements in buried piping are absorbed within a short distance (the influence length $L_\beta$) of changes in direction.

Within the influence length, soil springs may be spaced at a distance $L_i$ of approximately 2D, with individual spring stiffness $K_{s\text{-}oi,\, s\text{-}oj}$. Beyond the influence length, the springs may be spaced at larger distances $L_i$ such as 10D. This is shown schematically in Figure 5-6. In addition, beyond the influence length, three soil springs are spaced at a length of 2D on each side of any changes in piping direction. Examples of this are shown in Figure 5-7.

Soil springs can be modeled in a computer program first by creating three short members in the orthogonal directions of the pipe. The members are anchored at the endpoint and the appropriate stiffness is applied. The stiffnesses are calculated in the axial, transverse, and vertical directions.

## 4.8 Analysis of the Above Ground Metal Piping

In some instances, the anchor cannot be located at the building wall to completely isolate piping inside the building from the buried piping because of differential settlement or seismic anchor motion effects. In these cases the analysis methodology will include a portion of underground piping interacting with non-buried piping inside the building.

The piping analysis for the above ground steel Class 3 piping shall comply with the 2001 Edition through 2003 Addenda of ASME BPVC, Section III, Division 1, ND-3600 as described in Section 2.1.

## 4.9 Design Report (Stress Analysis Report)

The piping stress analysis Design Report shall have the same requirements as steel pipe. The Design Report is separate from the above ground steel piping. The design report shall include methodology, stress analysis inputs, relevant assumptions, computer codes and manual calculations, results, and conclusions that were used to qualify the use of HDPE.

The Design Report shall be stamped by a qualified Professional Engineer who has at least 18 months of experience with ASME Section III Class 3 piping as well as some relevant experience/knowledge of HDPE piping systems.

# 5.0 PIPING MODELING TECHNIQUES

## 5.1 Methodology and Approach

The piping system is analyzed using a combination of manual calculations and computer code. Piping analysis software that is used must be verified and validated in accordance with the Certificate Holder's Quality Assurance Program. The piping analysis software analyzes the complex piping systems subjected to static and dynamic loads. The basic load case (deadweight, pressure, thermal, seismic, SSE, etc.) and their combinations are included in the computer analysis.

Stresses in steel pipe can be automatically calculated by the computer software according to the pertinent ASME Code year; however, computer software does not currently calculate the stresses for all piping load cases and combinations for HDPE pipe since HDPE material properties and qualification criteria have not been included in these software packages. Consequently, manual calculations are performed for HDPE piping in accordance with this Topical Report.

### 5.1.1 Steel Pipe Criteria

The steel pipe, which extends from the building anchor to the HDPE pipe flange connection, is qualified using the computer software in accordance with the applicable codes.

## 5.2 Structural Boundaries

The model of a piping system typically begins and ends at anchor points, such as stiff equipment nozzles or fully constrained wall penetrations. These are points that effectively restrain all six degrees of freedom. If there are no anchors, the model could become very large and difficult to analyze. The boundaries required in this Topical Report will be on the metal side of the HDPE/steel interface.

## 5.3 Flexibility of Mitered Elbow Fittings

The response of a piping system due to a dynamic excitation, such as an earthquake, depends on the system's natural frequencies, which, in turn, depend on the flexibility of its fittings (tees, elbows, bends, etc.). The flexibility of fittings must therefore be correctly modeled. The flexibility of a pipe fitting is defined by a flexibility factor "k" (not to be confused with Service Level Factor) provided in the ASME Code, and is automatically calculated in piping analysis computer codes. The flexibility factor is used to calculate the SIFs and Stress Indices for the fitting. As noted in Section 4.6, specific SIF values for HDPE mitered elbows are given in Table 3-5 and Table 3-8. These tables cover all fittings allowed by this Topical Report except for flange adapters which have an SIF of 1.

## 5.4 Soil Springs

### 5.4.1 Soil Spring and Break Away Displacement

When a computer evaluation is used, the soil constraint on the pipe is modeled as distributed bilinear springs in each direction. There are four spring stiffnesses that vary depending on the direction:

- Transverse (horizontal, perpendicular to the pipe)
- Axial (longitudinal, parallel to the pipe)
- Vertical up
- Vertical down

Due to the flexibility of the PE piping relative to the soil stiffness, the contribution to the overall stiffness from ovaling of the PE pipe is considered. This effect is not included in standard piping programs, except at certain fittings which include the effect of ovaling due to bending loads. For PE pipe, when the soil pushes against the pipe the overall deformation is a function of both deformation of the soil and the pipe deformation due to ovaling.

The spring stiffness is considered linear with a stiffness $f_i/d_i$ in an analysis until the breakaway force is reached, beyond that point the stiffness between the pipe and the soil is considered to be small. The value of the breakaway force, $f_i$, and displacements, $d_i$, can be obtained from Table 5-1.

The following section outlines the methodology used to calculate the various directional stiffness of the combined soil/PE pipe ovaling springs.

### 5.4.2 Stiffness Due to PE Piping Ovaling

The stiffness due to pipe ovaling in any given direction perpendicular to the pipe (either transverse, vertical up, or vertical down) for a length of piping is calculated for an OD controlled pipe (Reference 13.7.1, EPRI Report 1013549),

$$K_{po} = \frac{2}{D_i}\left(\frac{\frac{2E}{3}\left(\frac{1}{DR-1}\right)^3 + 0.061E'}{K_b L}\right)DL_i$$

and for ID controlled pipe,

$$K_{po} = \frac{2}{D_i}\left(\frac{\frac{2E}{3}\left(\frac{1}{IDR+1}\right)^3 + 0.061E'}{K_b L}\right)DL_i$$

Where,

$K_{po}$ = Stiffness due to pipe ovaling
$D_i$ = The inside diameter of the pipe, in.
$D$ = The outside diameter of the pipe, in.

$DR$ = Pipe Dimension Ratio, $DR=D/t$
$IDR$ = Pipe Dimension Ratio for ID controlled pipe, $IDR = D_i/t$
$K_b$ = The bedding factor, usually 0.1
$L$ = The deflation Lag Factor, (1.0 recommended for seismic loads and 1.5 for thermal loads)
$E'$ = The soil reaction modulus, psi
$E$ = The pipe elastic modulus, psi, use short term modulus for seismic, and 1000 hr. modulus for thermal loads
$L_i$ = Effective length of piping modeled by discrete spring

The stiffness is based on one-half of the deflection of the ring and calculates the stiffness (in/lb) for a discrete spring of this effect that is distributed along the length and diameter of the pipe.

5.4.3 Soil Spring Calculation Method #1

This methodology models the soil stiffness in the transverse (horizontal, perpendicular to the pipe), vertical up, and vertical down directions. This will calculate $k_v$ the vertical modulus (psi) of subgrade reaction, $k_h$ the horizontal modulus (psi) of subgrade reaction, and $k_{ij}$ the orthogonal soil spring (lb/in) in the pipe. The effect of the axial friction force on the pipe is modeled in Appendix VII of ASME B31.1 by applying a force that is defined as $F_f$, the total friction force at the changes in direction of the pipe.

When using this method $k_v$ and $k_h$ are the parameters for K in defining the ovaling stiffness. The stiffness used for the combined soil/pipe ovaling that should be modeled is defined using the springs in series as follows (Reference 13.7.1, EPRI Report 1013549):

$$\frac{1}{K_{s-oi,s-oj}} = \frac{1}{K_{po}} + \frac{1}{K_{ij}}$$

Where,

$K_{s-oi,s-oj}$ = Combined soil-ovaling spring in a given direction,

$K_{po}$ = spring due to pipe ovaling calculated in Section 5.4.2

$K_{ij}$ = spring stiffness in a given direction calculated using the methodology in ASME B31.1, Appendix VII.

5.4.4 Soil Spring Calculation Method #2

The piping may be modeled using soil springs in all four directions, transverse (horizontal, perpendicular to the pipe), axial to the pipe, vertical up and vertical down, using the equations provided in ASCE guidelines for oil and gas transmission lines. Table 5-1 provides equations for $f_i$ (force in a given direction) and $d_i$ (displacement in a given direction), which are taken from ASCE guidelines.

Table 5-1: Equations to Calculate the Breakaway Force $f_i$, and Displacement $d_i$

| Soil | Transverse Spring $f_t/d_t$ | Axial Spring $f_a/d_a$ | Vertical Down Spring $f_a/d_a$ | Vertical Up Spring $f_u/d_u$ |
|---|---|---|---|---|
| Sand | $f_t = D\gamma_{soil} H \times N_{qh}$<br>$d_t$= 2% to 10% (H+D/2) | $f_a = (\pi D/2)\lambda_{soil} H(1+K_o)\tan\delta$<br>$d_a$= 0.1 in. to 0.2 in. | $f_d = \gamma_{soil} HN_q D + \gamma_{Soil} D^2 N\gamma/2$<br>$d_d$ = 10% to 15%D | $f_u = D\gamma_{soil} H \times N_{qv}$<br>$d_d$ = 0.5% to 1.5%D |
| Clay | $f_t = DS_U N_{ch}$<br>$d_t$= 3% to 5% (H+D/2) | $f_a = \pi DC_a$<br>$d_a$= 0.2 in. to 0.4 in. | $f_d = 5.14DS_u$<br>$d_d$ = 10% to 15%D | $f_u = D\gamma_{soil} H \times N_{cv}$<br>$d_d$ = 10% to 20%D |

where:

$D$ = Outer Diameter of the pipe, in.
$d_i$ = Displacement, in.
$f_i$ = Breakaway force, lb
$\gamma_{soil}$ = Density of soil, lb/in$^3$
$H$ = Height of the soil, in.
$N_{qh}$ = Horizontal capacity factor for sand (varies with H/d and ø, refer to Figure 5-1.)
$K_o$ = Coefficient of soil pressure at rest (0.5 to 1.0)
$\delta$ = Friction angle pipe-soil (deg), δ clay = 0, δ sand = 0.5ø to 0.8 ø
$N_{qv}$ = Vertical up-bearing capacity factor for sand (varies with H/d and ø, refer to Figure 5-4)
$N_{cv}$ = Vertical up-bearing capacity factor for clay (varies with H/d, refer to Figure 5-5)
$N_q$ = Downward bearing capacity factor 1 for sand (varies with ø, refer to Figure 5-3)
$N_{ch}$ = Horizontal bearing capacity for clay (varies with H/d and ø, refer to Figure 5-2(b))
$N_\gamma$ = Downward bearing capacity factor 2 for sand (varies with ø, refer to Figure 5-3)
$C_a$ = Soil adhesion (psi) (consisting of α x $S_u$ where $S_u$ is the undrained shear strength and α is a constant varying with $S_u$, refer to Figure 5-3 for factor)
$S_u$ = Undrained shear strength for clay (calculated from pile driving data)

Figure 5-1: Horizontal Bearing Capacity Factor for Sand as a Function of Depth to Diameter Ratio of Buried Pipelines, "Guidelines for the Seismic Design of Oil and Gas Pipeline Systems," 1984, ASCE

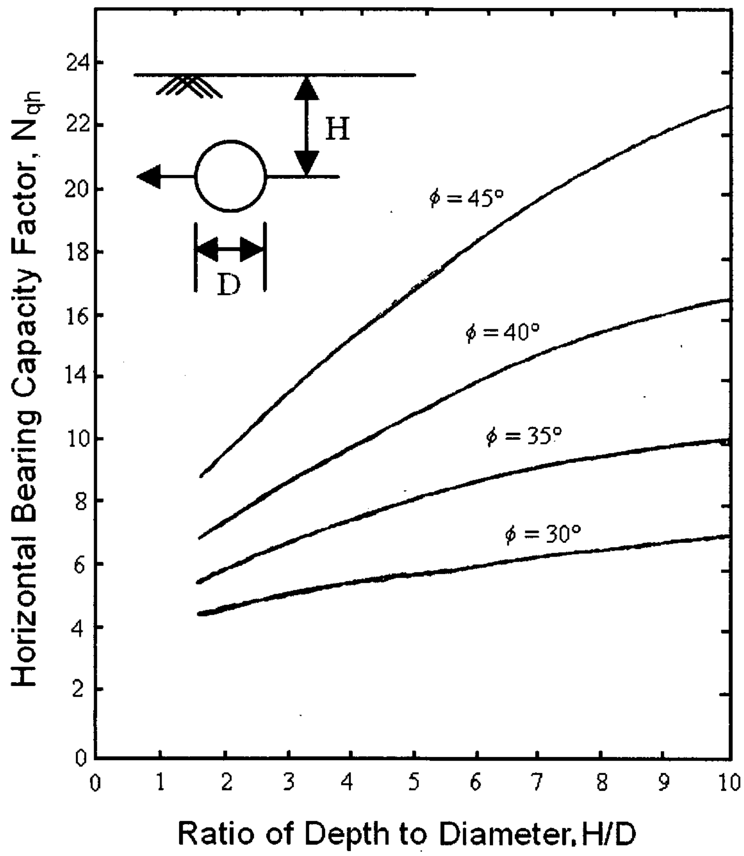


Figure 5-2: Horizontal Bearing Capacity Factors as a Function of Depth to Diameter Ratio for Pipelines Buried in Sand (A) and Clay (B), "Guidelines for the Seismic Design of Oil and Gas Pipeline Systems," 1984, ASCE

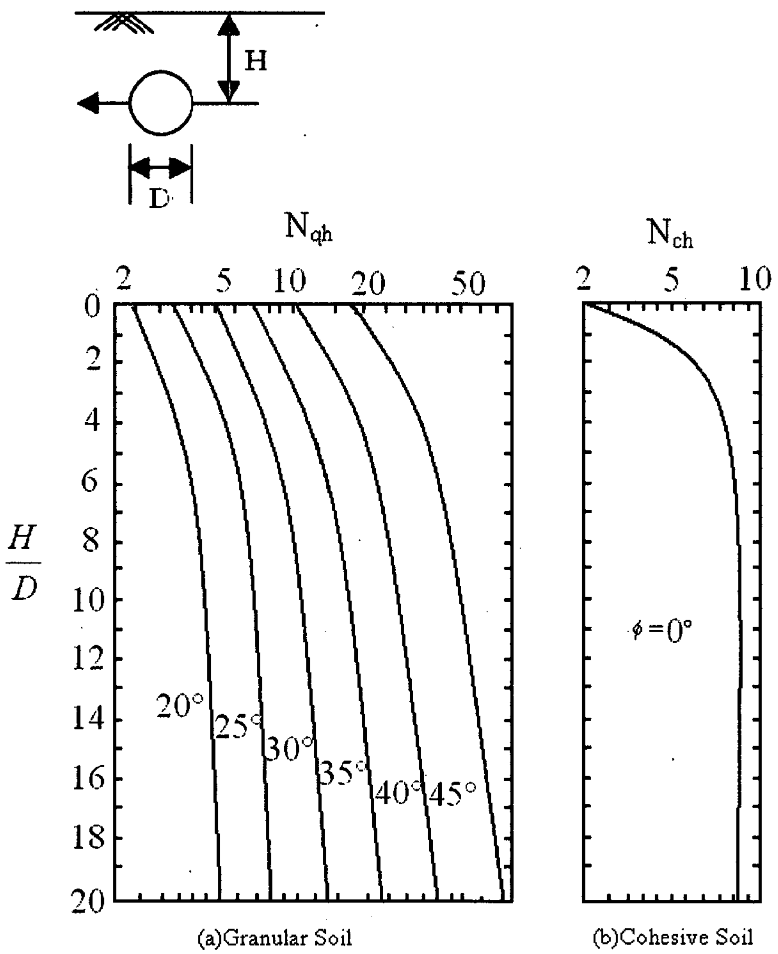


Figure 5-3: Vertical Bearing Capacity Factors vs. Soil Angle of Internal Friction for Sand, "Guidelines for the Seismic Design of Oil and Gas Pipeline Systems," 1984, ASCE

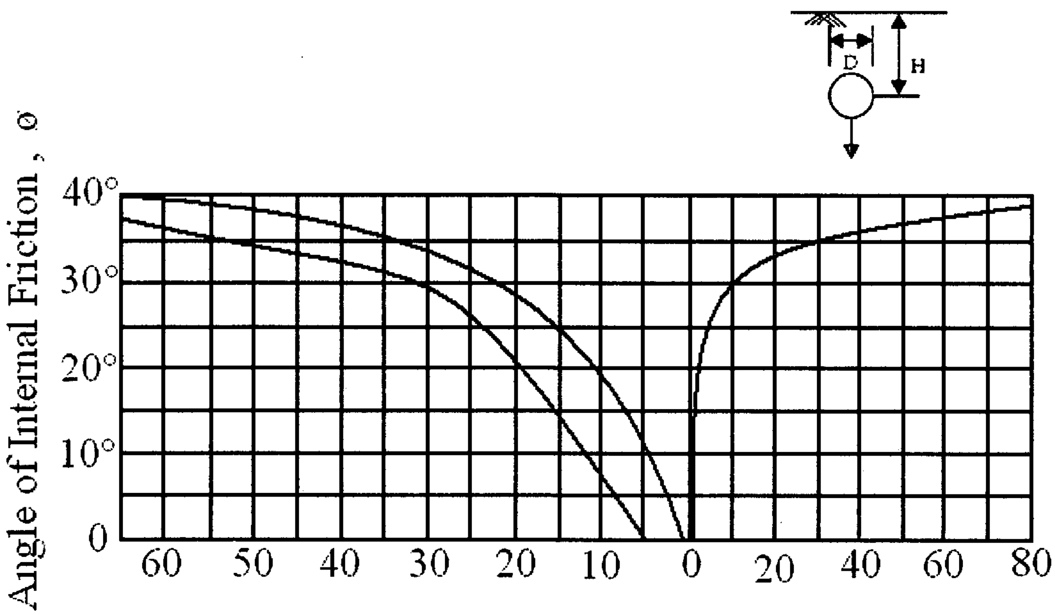



Figure 5-4: Vertical Uplift Factor for Sand as a Function of Depth to Diameter Ratio of Buried Pipelines, "Guidelines for the Seismic Design of Oil and Gas Pipeline Systems," 1984, ASCE

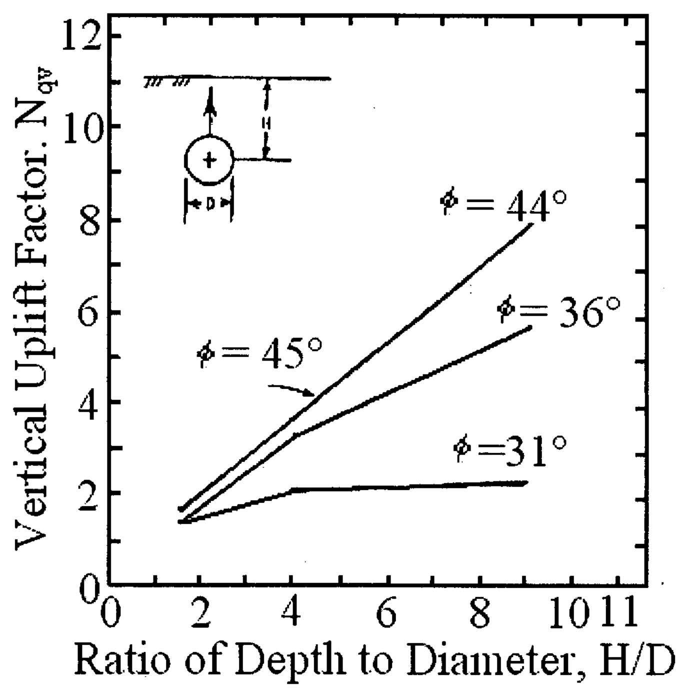
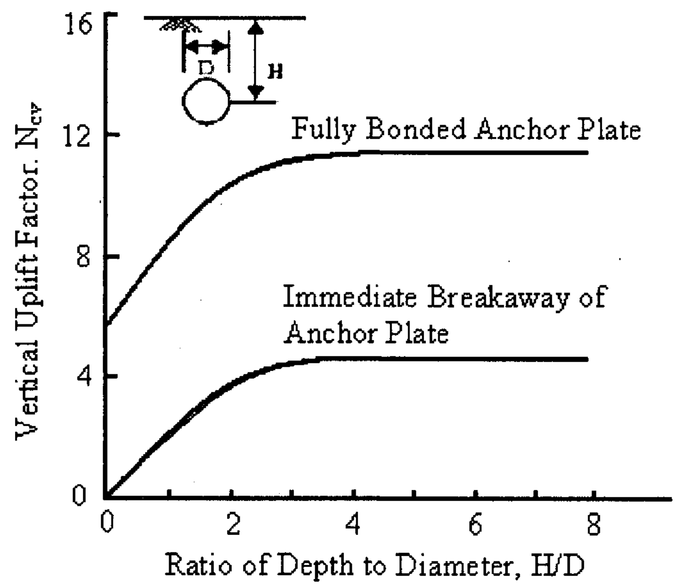


Figure 5-5: Vertical Uplift Factor for Clay as a Function of Depth, $D_o$, Diameter Ratio of Buried Pipelines, "Guidelines for the Seismic Design of Oil and Gas Pipeline Systems," 1984, ASCE




Using the previous formulation, the modulus (psi) of subgrade reaction in a given direction $k_i$ is given by the formulation for the transverse, vertical up, and vertical down springs as shown in the following equation,

$$k_i = f_{ij}/D$$

where,

$f_{ij}$ = force, f, lbs, calculated using the formulations in Table 5-1.
$D$ = outer diameter of pipe, in.

When using this method, $k_i$ is the parameter E′ in defining the ovaling stiffness discussed in Section 5.4.2. The spring stiffness for the soil is given by the following equation,

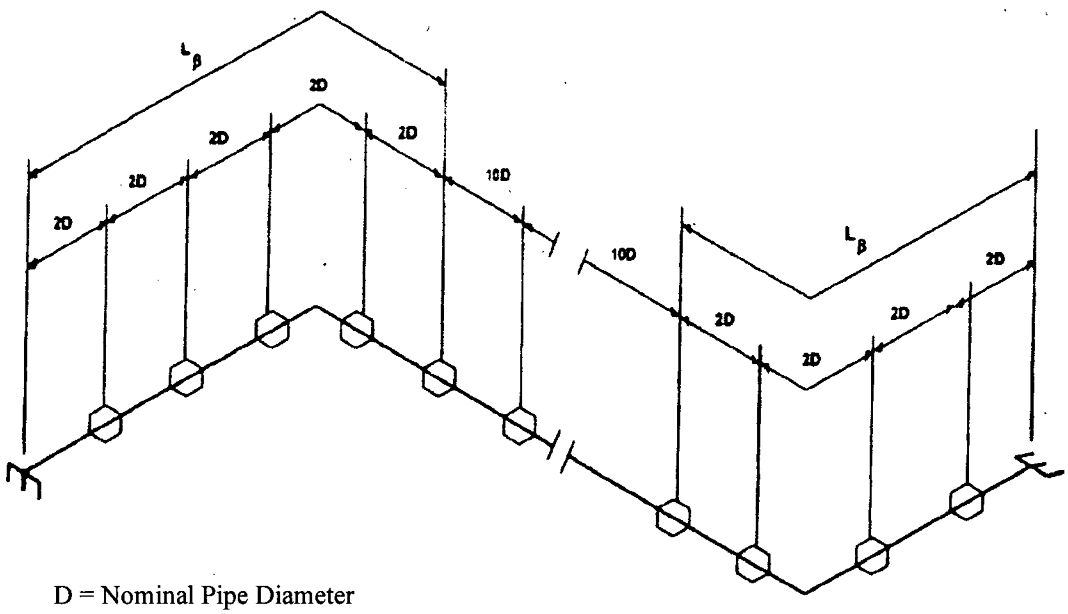
$$k_{ij} = f_{ij} \times L_i / d_{ij}$$

where,

$f_{ij}$,$d_{ij}$= force, f, and displacement, d, calculated using Table 5-1.
$k_{ij}$ = spring stiffness in a given direction calculated using the formulations in Table 5-1.
$L_i$ = The effective length of piping modeled by the discrete spring as shown in Figure 5-6 and Figure 5-7.

The spring stiffness in the vertical direction is adequately modeled using an average of the vertical up and down springs calculated using $k_{ij}=f_{ij} \times L_i/d_{ij}$. The spring stiffness used for the combined soil/pipe ovaling behavior that should be modeled is defined using springs in series equations. The axial spring is modeled using $k_{ij}=f_{ij} \times L_i/d_{ij}$ and does not require correction for ovaling.

Figure 5-6: Computer Modeling With Soil/Pipe Ovaling Springs




D = Nominal Pipe Diameter
$L_\beta$ = Influence Length

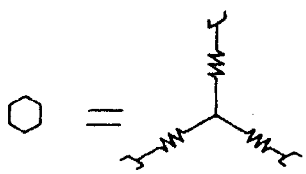
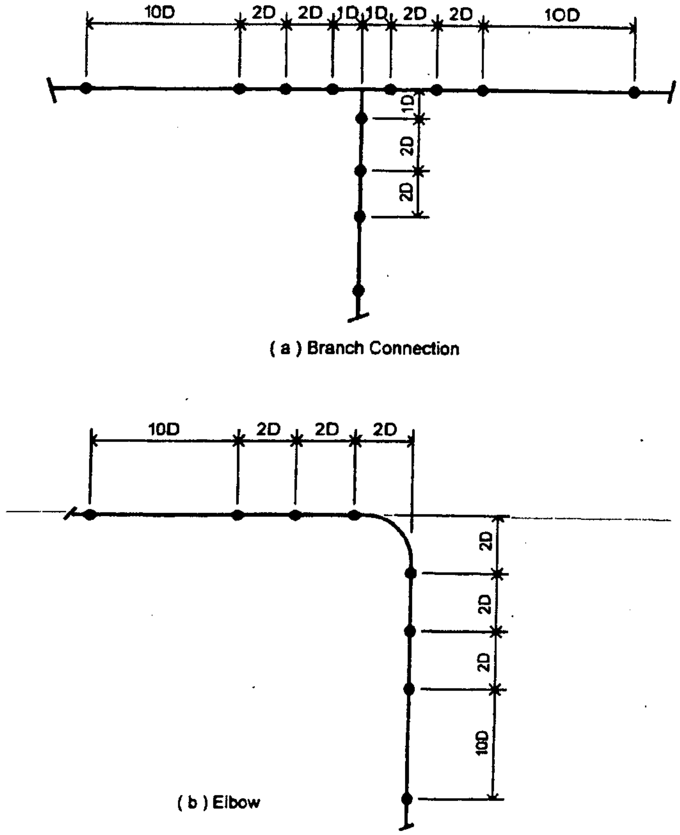


Figure 5-7: Modeling of Soil/Pipe Ovaling Springs At Changes in Direction Beyond the Influence Length




( a ) Branch Connection

( b ) Elbow

## 5.5 Vertical Piping Runs

For vertical piping there are no significant concerns with trench loading and surface loading creating a lateral crushing load on the piping. For these loadings, the lateral piping runs preceding or following the vertical run will, in most cases, control the design of the buried piping system. Therefore, explicit consideration of the trench and surface loading for vertical runs of buried piping is not required.

When using computer analysis for thermal and seismic loadings, vertical piping runs are considered essentially the same as horizontal piping runs in determination of the influenced length, however, for vertical piping, the soil spring stiffness is applied as follows:

1. The transverse soil spring stiffness should be applied in each of the two orthogonal directions.
2. The axial soil spring stiffness should be applied in the vertical direction.

In addition, the thermal expansion and axial strains shall also be applied to the vertical piping runs (in the axial direction). For vertical piping runs, the through wall trench bending stress may be taken as zero.

# 6.0 PIPE SUPPORT DESIGN CRITERIA

## 6.1 General

The HDPE piping will be buried in the ground and supported by the soil. Once the pipe is buried underground, the weight of the soil covering the pipe will restrain the piping against the effects of buoyancy forces due to ground water. Piping shall be placed in the ground and buried in such a manner as to prevent damage to the piping.

## 6.2 Temporary Supports for Inspection

The buried pipe will require a visual inspection of the fused joints and shall be supported by the engineered back fill in a manner that will hold the pipe in place during testing while still leaving the joint accessible for examination.

## 6.3 Building Anchor Movements

The only mechanical pipe support in the HDPE piping systems will be the anchor at the building penetration where the metallic pipe exits the building. These supports will be designed to ASME Section III, Division 1, subsection NF. The movements due to building expansion/settlement as well as seismic anchor movements shall be analyzed. Movements less than 1/16" are not required for the piping analysis.

# 7.0 INSTALLATION REQUIREMENTS

## 7.1 General Requirements

### 7.1.1 Scope

Methods of fabrication and installation is by straight HDPE pipe, butt fusion joints, two segment, three segment and five segment mitered elbows (made from HDPE pipe), and HDPE to metallic flanges. Use of threaded or adhesive joints with PE material is not permitted. Metallic interface items will be installed following the requirements of ASME Section III, Subsection ND.

### 7.1.2 Examinations

Examinations are performed by QA/QC personnel. These visual examinations are required to be performed by personnel and procedures qualified to the requirements delineated in Sections 8.2.1 and 8.4, respectively.

### 7.1.3 Repair of Material

HDPE pipe originally accepted on delivery in which defects not exceeding the limits in Section 10.4.1 are discovered may be used if the pipe is repaired per Section 8.1.1.B or the defective area is physically removed.

### 7.1.4 Material Identification

A. Material for pressure retaining parts will carry identification markings which will remain distinguishable until the component is assembled or installed. If the original markings are cut off or the material is divided, the same marks will be transferred to the cut parts or a coded marking will be used to assure the identification of the material during subsequent installation. An as-built sketch or a tabulation of materials will be made identifying each piece of material with a Certificate of Analysis or Certified PE Test Report, where applicable, and the code marking.

B. Material from which the identification marking is lost or not legible for traceability is treated as non-conforming material until verifications are made and documented to assure material identification. Testing is required unless positive identification can be made by other documented evidence. The material shall then be marked in accordance with the requirements of Section 10.3.1 to restore proper identification.

## 7.2 Cutting and Bending

### 7.2.1 Cutting

Materials may be cut to shape and size by mechanical means such as machining or cutting.

### 7.2.2 Bending

The following requirements shall apply to the forming and bending processes used in the fabrication and erection of Polyethylene pipe:

A. The longitudinal wall strain in a curved pipe is proportional to the bend ratio. Generally, the strain capacity of polyethylene is sufficiently safe for a bend ratio of 30 for piping with a DR 6 through DR 17, except within two pipe diameters of a flange connection or mitered elbow (measured from the pipe component to joint fusion weld); however, there is another limit to bending. Longitudinal bending induces ovality in the ring direction of the pipe, thus reducing the resistance to kinking. Thicker wall pipes have higher resistance to kinking and, therefore, can safely withstand more curvature than thinner wall pipes. Temporary curvature is less likely to cause kinking than permanent curvature since PE's modulus decreases with time under load, therefore, the minimum bend ratio depends on the DR and the duration of curvature. Table 7-1 contains minimum long-term bend ratios for pipe. This tolerance shall not be used in lieu of a mitered elbow.

Because fittings and flanges are rigid compared to pipe, the minimum bend ratio must be increased to 100 where fittings or flanges are present in the curve.

Table 7-1: Minimum Bend Ratio for HDPE Piping

| Dimension Ratio, DR | Minimum Bend Ratio, α |
|---|---|
| 6 | 20 |
| 7 | 20 |
| 7.3 | 20 |
| 9 | 20 |
| 11 | 25 |
| 13.5 | 25 |
| 17 | 27 |

R = Bend Radius, $\alpha \times (OD)$

OD = Pipe Outside Diameter

B. The Polyethylene material shall not be cold or hot bent.

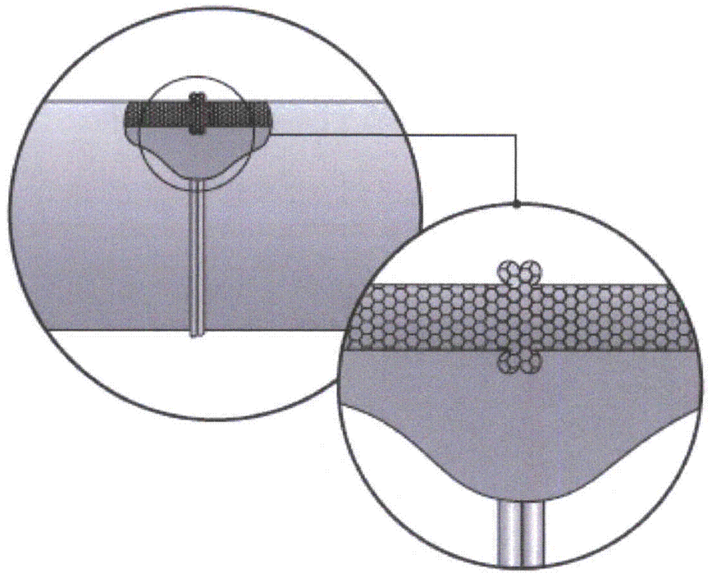
## 7.3 Fusing Qualifications

### 7.3.1 General Requirements for Fusion Qualification

A. Fusing procedure and machine operator performance qualification shall comply with the requirements of Sections 8.6 and 8.7.

B. The thermal fusion butt joint is the only thermal fusion joint allowed for use in this Topical Report:

Figure 7-1: Thermal Fusion Butt Joint



### 7.3.2 Qualifications

A. Required Qualifications

The Certificate Holder is responsible for fusing and shall establish the procedure and conduct the tests required by this Topical Report in order to qualify both the fusing procedures and the performance of fusion machine operators who apply these procedures.

B. Maintenance and Certification of Records

The Certificate Holder will maintain records of qualified fusing procedures and the fusion machine operators qualified by them, showing the date and results of tests and the identification mark assigned to each fusing operator. These records will be reviewed, verified, and signed by an authorized individual assigned by the Certificate Holder and they will be accessible to the Authorized Nuclear Inspector.

C. Fusing Prior to Qualification

Fusing will not be undertaken until after the Fusion Procedure Specification (FPS) is qualified. Only fusion operators who are qualified in accordance with Sections 7.3, 8.6 and 8.7 of this Topical Report shall be used.

D. Transferring Qualifications

The FPS qualifications and performance qualification tests for fusion machine operators conducted by one Certificate Holder are not transferable to another Certificate Holder.

7.3.3 Requirements for Fusing Procedure Qualifications Tests

A. Conformance to Sections 8.6 and 8.7 Requirements

Fusing procedure qualification tests shall be in accordance with the requirements of Sections 8.6 and 8.7.

B. Preparations of Test Coupons and Specimens

Removal of test coupons from the fusion test coupon and the dimensions of specimens made from them shall conform to the requirements of Sections 8.6 and 8.7.

7.4 Rules Governing Making Fused Joints

7.4.1 General Requirements for Making Fused Joints

A. Identification, Storage, and Handling of PE Materials

The Certificate Holder is responsible for control of PE materials that are used in the fabrication and installation of components. Suitable identification, storage, and handling of PE material will be maintained.

B. Cleanliness and Protection of Surfaces to be Fused

The fusing surfaces will be free of scale, rust, oil, grease, and other deleterious material. The work will be protected from deleterious contamination and from rain, snow, and wind during fusing operations. Fusing will not be performed on wet surfaces.

7.4.2 Rules for Making Fused Joints

A. Fused Joint Fit-up Requirements

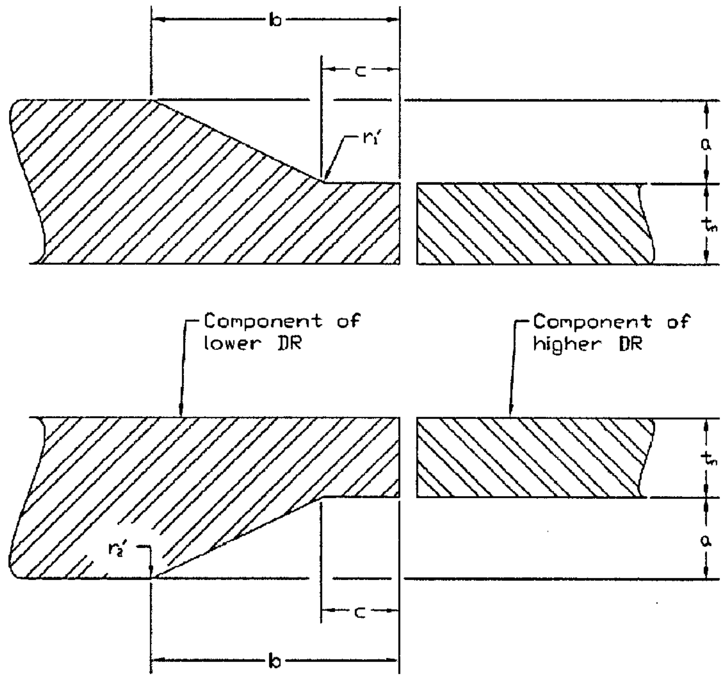
1) Components of different outside diameters will not be fused together.

2) The alignment of components for open butt fusion joints will be held in position by the fusing machine. The outside diameters of piping components to be fused will be aligned as accurately as practical within existing commercial tolerances on diameters, wall thicknesses, and out of roundness.

Alignment will be preserved during fusion. The external misalignment of the ends to be joined will not exceed 1/16".

3) To fuse components with differing DR's, the component with the smaller DR will be machined and tapered to meet the wall thickness of the component with the larger DR and shall comply with Figure 7-2, External Pipe Wall Transition Taper.

Figure 7-2: External Pipe Wall Transition Taper




$t_n$ = nominal thickness of thinner component
$c_{min}$ = 2.5 $t_n$ (c values are after facing)

Taper Slope: $\left[\frac{a}{(b-c)}\right]_{max} < 0.60$ and, $\left[\frac{a}{(b-c)}\right]_{min} > 0.30$

$r_1'_{min} = 0.05t_n$ $r_2'_{min} = 0.05t_n$

B. Identification of Joints by Fusing Operator

Each fusing operator will apply the identification mark assigned to him by the Certificate Holder adjacent to all permanent fused joints or series of joints on which he fuses. The marking will be 1ft or less from the fusion bead and will be done with permanent metallic paint marker or stenciling marker.

External and internal fusion beads are not part of the pressure boundary and can be removed at any time.

C. Minimum Ambient Temperature

Fusion is performed with a minimum ambient temperature of 50°F. If the ambient temperature is not suitable for fusion (<50°F), a tent will be erected around the fusion joint being made to control the climate around the joint.

D. Repairs

Repair of a fused joint is not allowed. Unacceptable joints are cut out and replaced.

7.4.3 Fusion Data Acquisition Recorder

The fusion machine shall have a data acquisition recorder attached to it. The data acquisition record produced by the device shall include important information of the fusion process as show in Section 8.6.1 to record essential variables of the fusion process.

A. Failure to run the recorder during the fusion process shall cause rejection of the fusion joint.

B. The data acquisition records shall be compared to the FPS to ensure that the requirements of the FPS were met. If any FPS requirements, not limited to the essential variables is out of the approved range, the fuse joint shall be cut out and remade.

7.5 Fabrication and Assembly

7.5.1 General Assembly Requirements

Alignment of joints for assembly could result in piping distortion greater than the requirements of Section 7.2.2. This may result in the introduction of a permanent strain in the piping components and is prohibited.

7.5.2 Flanged Joint Using HDPE Material to Steel Flanged Joints

All connections of PE to steel piping will be made using a PE to steel flanged joint. See Figure 7-3 for a typical PE to metal flange configuration. For a uniform hydraulic design, the HDPE pipe is sized to approximately match the steel pipe's ID. When the PE pipe OD is one or more pipe sizes larger than the steel pipe, a steel reducing flange will be used to match the sealing surface face area of the PE flange adapter (not shown in Figure 7-3).

A. The PE flange connection will be constructed using a PE flange adapter having a DR or SDR equal to or less than that of the attached PE pipe.

B. The PE flange adapter will be connected to the steel mating flange using a steel backing ring. The backing ring will have a design pressure rating equal to or greater than the metal flange. The pressure rating and design of the steel flange will meet the requirements of ASME Section III, ND-3647.

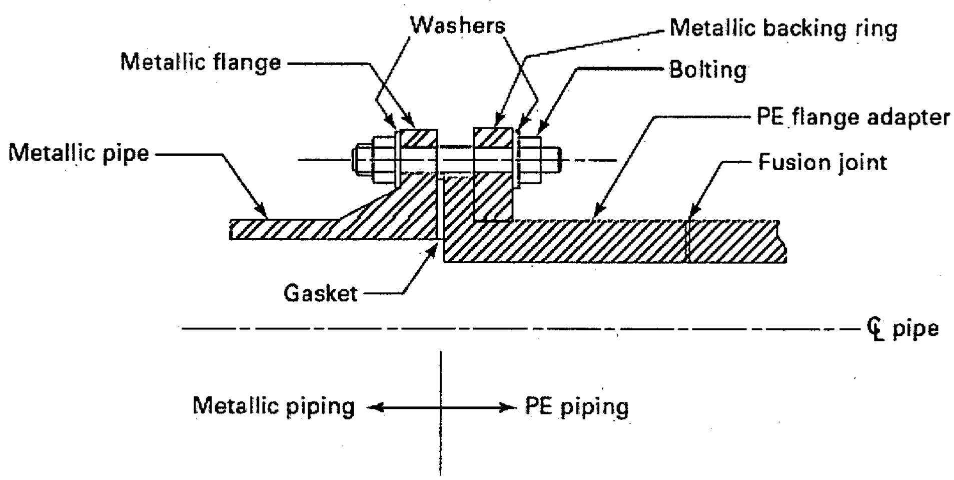
C. Before bolting up, flange faces shall be aligned to the design plane within 1/16" inch. If measured across any diameter; flange bolt holes shall be aligned within 1/8" inch maximum offset.

D. The flanges are joined using bolts of a size and strength that conforms to the requirements of ASME Section III and ASME B16.5 or B16.47 as applicable. Bolts or studs shall extend completely through the associated nuts. Hardened flat washers are used under bolt heads and nuts.

E. The use of a gasket is optional for smaller pipe sizes, but is required when steel reducing flanges are used. If used, no more than one gasket is used between contact faces in assembling a flanged joint.

F. The flange bolts are tightened to the minimum torque values required for sealing against the maximum sustained internal pressure and transient surge pressures specified in Section 3.10.4. Criteria in PPI TN-38 will be used to establish the required bolt torque.

Figure 7-3: Transition Flange Arrangement




7.6 Excavation and Backfill

7.6.1 Excavation and backfill will be in accordance with codes and standards referenced in Section 2.0, as applicable, including ASTM F1668 and ASTM D2774. Trenches shall be near vertical where possible. These Codes and Standards identify minimum standards required for backfill. Site specific structural fill requirements may be instituted if demonstrated to be more stringent than the basic requirements.

7.6.2 Unless shown otherwise on drawings, depth of cover over pipes shall be a minimum of 3 feet from the top of pipe to finished grade.

7.6.3 Trenches will be kept free of water during construction by use of dewatering equipment. When trench bottom is reached, any unusual conditions shall be evaluated prior to proceeding with the setting of pipe. Trenches shall be excavated to the required depth to ensure uniform bearing of the bedding.

7.6.4 Pipe fittings and accessories are carefully inspected for defects before installation. Defective, unsound or damaged materials will be rejected and replaced.

7.6.5 No shims or lumps of soil will be used to adjust the pipe to grade.

7.6.6 Pipe will be bedded in compacted granular material placed on a flat trench bottom. The granular material shall be crushed stone, sand or pea gravel which shall pass a 1/2" sieve, but shall be retained by a No. 4 sieve. The granular material bedding shall have a minimum thickness of one-fourth the pipe diameter and shall extend halfway up the pipe barrel at the sides.

7.6.7 The remainder of the side fills and a minimum depth of 12" over the top of the pipe shall be filled with carefully compacted material. Backfill will be well tamped in layers not more than 6" deep under and around pipes to, as a minimum, a 90% standard proctor per ASTM D698 to prevent settlement or lateral movement, and shall contain no ashes, cinders, refuse or other corrosive material. Rock shall not be placed in trenches. Backfill under roads and structures shall meet, as a minimum, 95% proctor per ASTM D1557.

7.6.8 Partial backfilling between pipe joints will be required to prevent pipe movement during the hydro test.

7.6.9 Pipe bedding and cover materials will be monitored by an inspector using field moisture-density tests. Field results will be compared to laboratory moisture-density tests to ensure that the required compaction density is attained and that the material is being placed with proper moisture. Proper compaction is necessary to verify soil design properties are met. Laboratory moisture-density tests will be performed on each material to be used as fill. Fill will be characterized by material gradation of on-site material or from qualified off-site borrow areas. Frequency of tests will be specified. Unique site soil conditions may require different bedding and backfill.

7.6.10 The precautions necessary to protect the HDPE pipe from damage will conform to the requirements listed in ASTM D2774 and ASTM F1668.

# 8.0 INSPECTIONS AND TESTS

## 8.1 Materials

### 8.1.1 Examination of Materials

A. Receipt Examination

1) PE material external surfaces shall be given a visual examination prior to installation. Any indentation that does not meet the requirements of Section 10.4.1 shall be unacceptable.

2) Personnel performing the examination are qualified in accordance with the Codes and Standards referenced in Section 8.4.

B. Repair of PE Material

The Non Conformance Reporting (NCR) process will be used to document as found conditions and repair of HDPE pipe.

Pipe surface gouges or cuts that are less in depth than the defect described in Section 10.4.1 and do not interfere with the minimum required wall thickness, may be removed by grinding or machining in accordance with the following requirements.

The repaired pipe may be used as-is provided:

1. The removed area has a minimum taper of 3:1 without sharp edges (width: height), and,
2. The remaining wall thickness is in excess of $t_{design}$ required by this Topical Report.

If the damaged area is in the flange face, the entire flange can be removed or the face can be refaced.

### 8.1.2 PE Material Fusing Qualification Testing

See Section 10.3.4.

## 8.2 Examination Procedures

### 8.2.1 General Examination Requirements

A. Visual examinations are conducted in accordance with the examination method of the 2001 Edition through 2003 Addenda of the ASME BPVC Section V, Article 9.

B. Ultrasonic examinations are conducted in accordance with the requirements of the 2001 Edition through 2003 Edition of the ASME BPVC Section V, Article 4.

C. Personnel qualified to perform visual examinations on HDPE pipe installation, excluding the hydrostatic pressure test, will receive the same training as required for the fusion machine operator in Sections 8.6 and 8.7. Training will be documented on a training record. See Section 8.4 for personnel qualification requirements.

Personnel performing visual examinations required by Sections 8.2.4.D and 8.2.4.E will be qualified and certified as a VT-1 in accordance with IWA-2000 of ASME Section XI.

Personnel performing visual examinations required by Section 8.2.4.F will be qualified and certified as a VT-2 in accordance with IWA-2000 of ASME Section XI and receive four hours of training in PE piping and joining practices.

D. Records pertaining to procedure and personnel qualifications and examinations of materials and joints will be retained in accordance with the Certificate Holder and/or Owner's Quality Assurance Program.

8.2.2 Required Examinations

The following visual examination and inspections shall be conducted:

A. Inspection of the general surface for indentations.

B. Fusion joints, including review and verification of fusion data for the joint

C. All fusion joints during the hydrostatic test (Section 8.5). For any fusion joints tested during the hydrostatic test, any fusion joint leakage shall cause rejection of the joint.

1) The visual examination shall be conducted by examining the accessible external exposed surfaces of pressure retaining components for evidence of leakage.

2) For components whose external surfaces are inaccessible for direct visual examination, only the examination of the surrounding area (including areas or surfaces located underneath the components) for evidence of leakage shall be required.

3) Flange leakage is excluded from this requirement.

8.2.3 Examination Procedures

A. Examinations performed are executed in accordance with detailed written procedures which have been proven by actual demonstration to the satisfaction of the Authorized Nuclear Inspector. Written procedures, records of demonstration of procedure capability, and personnel qualification are available to the Authorized Nuclear Inspector.

B. The nondestructive examination procedures are qualified using performance based demonstrations to assure that the examination process satisfactorily identifies rejectable conditions predicted on the acceptance criteria defined herein. The qualification demonstration will address material, configuration, pipe and fitting sizes and environmental conditions. The performance based demonstration is conducted and documented in accordance with the ASME BPVC Section V, Article 14.

### 8.2.4 Visual Examination of Completed Fused Joints

Visual examination of all fused joints are conducted:

A. Upon the completion of the cooling period

B. After the review required by Section 7.4.3 has been reviewed and accepted

C. Before piping is placed in the burial trench

D. During receipt inspection of the external surface for indentations, nicks, gouges, etc.

E. On fusion joints after the fusion process including a review and verification of fusion data for the joint and external surfaces. The examination evaluates the adjacent base material for at least two inches on either side of the joint.

F. On pipe fusion joints during the hydrostatic test.

### 8.2.5 Time of Flight Diffraction (TOFD)

To provide added assurance of joint integrity, an ultrasonic Time of Flight Diffraction examination is performed for all completed fused joints.

A. The provider of this examination must adhere to 10CFR50 Appendix B Program requirements.

B. A demonstration will be performed that verifies the Time of Flight Diffraction procedure applies available technology for this technique. The demonstrations shall include specimens containing 10 flaws of varying shapes and sizes to simulate flaws expected to occur in unacceptable joints.

C. Acceptance criteria will be evaluated and will be based on industry standards. Current acceptance criteria requires that any un-bonded area in a joint is cause for rejection.

D. Time of Flight Diffraction examination records are retained as permanent records.

E. Ultrasonic Examination of Completed Fused Joints (Time of Flight)

Ultrasonic examination of all fused joints will be conducted:

1) Upon the completion of the cooling period,
2) After the review required by Section 7.4.3 has been reviewed and accepted,
3) Before piping is placed in the burial trench,
4) Shall evaluate the adjacent base material for at least two inches on either side of the joint.

## 8.3 Acceptance Standards

Unacceptable joints are removed. Repair of unacceptable joints is not permitted.

### 8.3.1 Visual Examinations Acceptance Criteria of External Surfaces

Thermal Fusion Butt Joints shall meet the following:

A. Joints shall exhibit proper fusion bead configuration, (see Figure 8-2, Fusion Bead Configuration)

B. There shall be no evidence of cracks or incomplete fusion,

C. Joints shall not be visually angled or offset. The ovality offset shall be less than 10% of the minimum wall thickness of the fused components,

D. The cleavage between fusion beads shall not extend to or below the outside diameter pipe surface (see Figure 8-1, PE Pipe (Cross Section View)).

Figure 8-1: PE Pipe (Cross Section View)

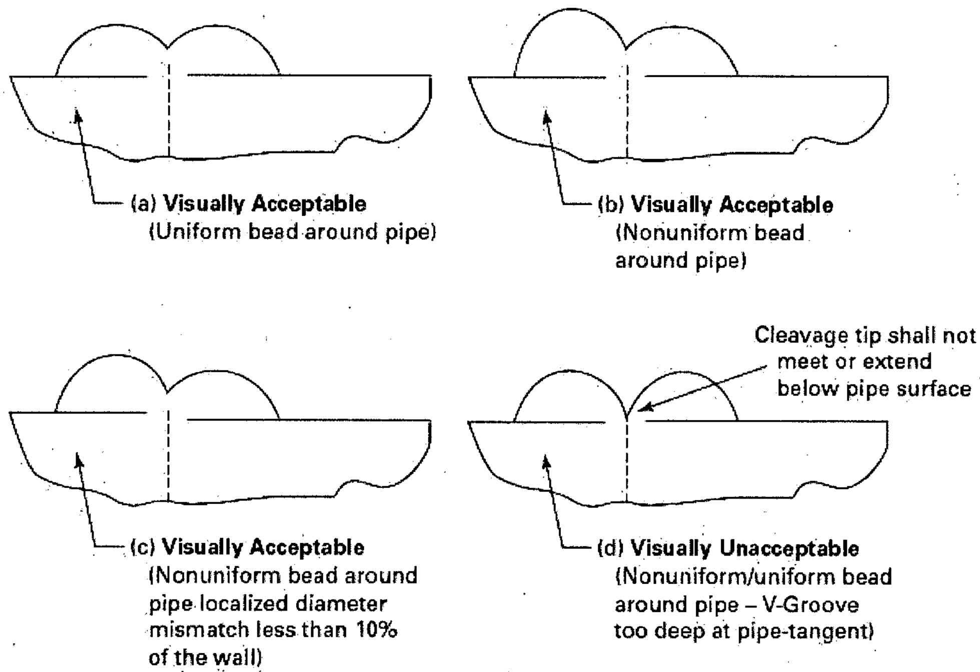
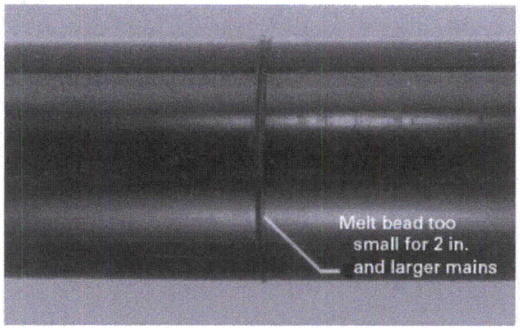
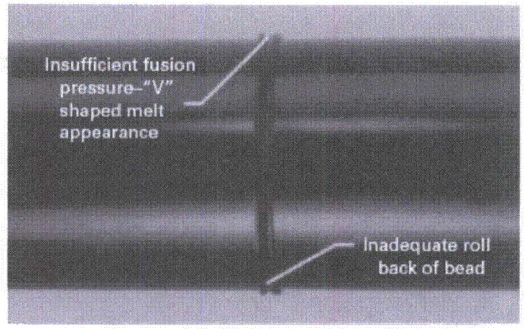


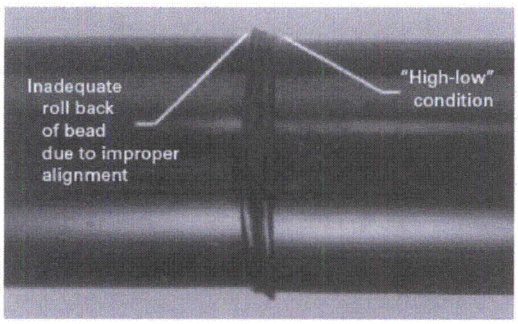
Figure 8-2: Fusion Bead Configuration



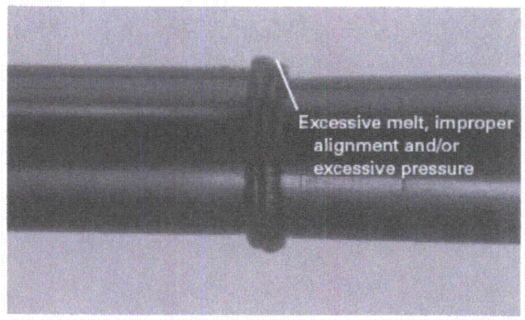

**(a) Butt Fusion of Pipe**
(Unacceptable appearance–insufficient melt)



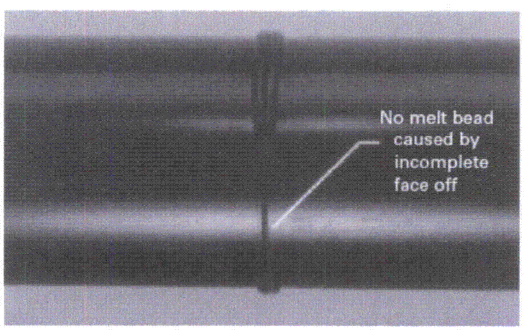

**(b) Butt Fusion of Pipe**
(Unacceptable appearance–inadequate roll back)



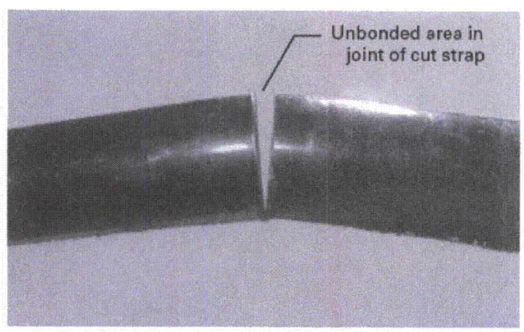

**(c) Butt Fusion of Pipe**
(Unacceptable appearance–improper alignment)




**(d) Butt Fusion of Pipe**
(Unacceptable appearance)




**(e) Butt Fusion of Pipe**
(Unacceptable appearance–incomplete face off)




**(f) Butt Fusion of Pipe**
(Unacceptable appearance–incomplete face off)

Note: This is only to be used as a guide.

8.3.2 Process Verification

The data acquisition record for each joint is reviewed and compared to the Fusion Procedure Specification (FPS) to ensure the proper parameters and procedures were followed in making the fused joint.

8.4 Qualification of Non-Destructive Examination Personnel

8.4.1 General NDE Qualification Requirements

Individuals performing Code required nondestructive examinations and/or evaluating the results will be qualified in accordance with ASME Section III, ND-5520 or ASME Section XI, Division 1, IWA-2300 as applicable.

Personnel performing visual and ultrasonic inspections will demonstrate their proficiency by performing an examination of physical samples of acceptable and unacceptable HDPE pipe fusion joints. A minimum of five flaw samples will be used for the visual examination procedure. In order to be considered qualified, personnel must identify at least 90% of the known defects in the test coupon.

8.4.2 Certificate Holder Requirements

A. Personnel performing visual and ultrasonic examinations are qualified in accordance with ASME Section III, ND-5520 and the Certificate Holder's NDE Program. This training is documented on a training record.

B. Personnel performing nondestructive examinations on material receipt and completed fused joints shall receive the required training in Section 8.2.1.C. Personnel performing only the hydrostatic test visual examination are not required to complete the training in Section 8.2.1.C, but are required to complete four hours of training in PE piping and joining practices. Training is documented on a training record.

8.4.3 Owner Requirements

A. Personnel who will be qualified to perform visual and ultrasonic examinations and data acquisition record review on HDPE piping, excluding the hydrostatic pressure test, will receive the same training as required in Sections 8.6 and 8.7. This includes the use of a fusion machine to make a simple fused joint; the fused joint is not required to be tested. Training is documented on a training record.

B. In addition to training required by the paragraph above, personnel performing visual examinations shall receive an additional 16 hours of training in HDPE piping and joining practices, documented on a training record.

## 8.5 Testing

### 8.5.1 General Requirements

A. Prior to initial operation, the installed system is hydrostatically tested in the presence of the Authorized Nuclear Inspector in accordance with the procedures and requirements of ASTM Standard F 2164.

B. All joints, including fused joints are left exposed for examination during the test. For long sections of piping, the hydrostatic testing may be accomplished by testing in small subsections of the longer section. Upon a satisfactory test of each small section the piping may be buried. This process shall be documented in the Certificate Holder's Quality Assurance Program or the Owner's Quality Assurance Program and found acceptable to the Authorized Nuclear Inspection Agency. The subsequent joint must be exposed for hydro testing upon completion of the fused joint.

C. The pressure in the test section shall be gradually (minimum rate of 5 psi/min not to exceed a maximum rate of 20psi/min) increased to the test pressure specified in 8.5.2.B below and held for four hours. Makeup water may be added to maintain test pressure during this time to allow for initial expansion. Following the four hour initial pressurization period, the test pressure shall be reduced to 1.5 times the Design Pressure and the system monitored for another one hour. Make up water may no longer be added to maintain pressure. Each joint shall be examined. The pass/fail hydro test acceptance criteria is described in ASTM F2164 Paragraph 9.8 (e.g., if no visual leakage is observed and the pressure remains within 5% of the test pressure for the one hour, the pipe section under test is considered acceptable).

D. The temperature of the piping under test will be maintained within the temperature limits of the system design.

E. The total test time including initial pressurization, initial expansion, and time at test pressure, must not exceed eight hours. If the pressure test is not completed the test section will be depressurized. The test section shall not be re-pressurized for at least eight hours.

F. A pneumatic test is not permitted.

### 8.5.2 Certificate Holder Hydrostatic Test Requirements

A. The piping system will be tested by hydrostatic test in accordance with ASME Section III, ND-6200.

B. The minimum test pressure shall be 1.5 times the Design Pressure of the PE piping system plus 10psig. The maximum test pressure shall be 1.5 times the Design Pressure of the PE piping system plus 20psig.

C. The test shall be conducted and documented by qualified personnel in accordance with the Certificate Holder's ASME QA Program.

## 8.6 Fusion General Requirements

The requirements in this Section apply to the preparation of the FPS and the qualification of fusion machine operators for thermal butt fusion. The minimum recommended training guidelines for fusion machine operators is provided in PPI TN-42/September 2009.

Some of the more common terms related to fusion are defined in Section 1.1 and ASTM F412-06, Standard Terminology Relating to Plastic Piping Systems.

A. Responsibility

1) Fusion

Each manufacturer or contractor is responsible for the fusing done by their organization. Tests shall be conducted to qualify the procedures used in the production of the fused joints made and the performance of fusion machine operators who use these procedures (Section 8.8).

2) Records

Each manufacturer or contractor shall maintain a record of the results obtained in the fusing procedure and fusion machine operator performance qualifications. These records shall be certified by the manufacturer or contractor and shall be accessible to the Authorized Nuclear Inspector.

3) Documents

A FPS is a written document that provides direction to the fusion machine operator for making fused joints. Any manufacturer or contractor that will have responsible operational control of production fusing shall have a FPS that has been qualified by that manufacturer or contractor in accordance with Section 8.7.

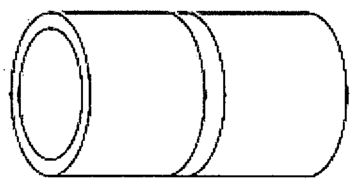
- The FPS specifies the conditions under which the fusing must be performed. These conditions include the HDPE materials that are permitted. Such conditions are referred to as the fusing "essential variables." When a FPS is to be prepared by the manufacturer or contractor, it shall address these essential variables.
- The purpose for the qualification of a FPS is to determine that the fused joint proposed for construction is capable of providing the required properties for its intended application. FPS qualification establishes the properties of the fused joint, not the skill of the fusion machine operator.

4) In performance qualification, the basic criterion established for fusion machine operator qualification is to determine the operator's ability to operate the fusing equipment to produce a sound fused joint.

B. Joint Orientation

The orientation of all fused butt joints produced for tests or production shall be made within +/- 45 degrees of the horizontal axis position illustrated in Figure 8-3.

Figure 8-3: Horizontal Axis Position



C. Training

Each fusion machine operator will receive a minimum of 24 hours of training, covering the principles of the fusion process and the operation of the fusion equipment. There will be a two part test at the end of this training; Part 1 Theoretical Knowledge and Part 2 Performance Qualification.

- The theoretical test shall cover as a minimum: safety, fundamentals of the fusing process, and recognition of typical joint imperfections.
- The Performance Qualification test is performed using an approved FPS.

8.6.1 The Fusion Procedure is qualified at the extreme range of essential variables. Any change in essential variables beyond the range for which it's qualified will require re-qualification.

A. Data Acquisition Record Evaluation

1) Data Acquisition Recorder

The data acquisition recorder will be capable of recording the following butt fusion essential variables on each joint:

*(1)* Equipment model number
*(2)* Pipe diameter
*(3)* Pipe wall thickness
*(4)* HDPE material type
*(5)* Fusion cycle times
*(6)* Fusion process temperature
*(7)* Heater surface temperature immediately prior to insertion of the heater plate

*(8)* External environment temperature
*(9)* Interfacial gauge pressure during the heating cycle
*(10)* Interfacial gauge pressure during the fusion/cool cycle
*(11)* The amount of time during the heat cycle
*(12)* The amount of time to open the fusion machine, remove the heater, and bring the pipe ends together at butt fusion pressure.
*(13)* Amount of time during the fusion and cool cycle

Job information related to the joints such as job number, joint number, employee number, time, date, fusion machine identification, pipe manufacturer, interfacial pressure, drag pressure, and pipe material will also be documented.

The data acquisition recorder must be capable of storing at least one days worth of butt fusion joint information and capable of downloading the information as a permanent record.

2) Data Acquisition Log Evaluation

The butt fusion joint record will be compared to the FPS to ensure that the proper butt fusion parameters and procedures were followed. If they were not, the joint shall be cut and a new joint fused using the correct parameters and procedures per the FPS. An example of a Data Acquisition Log review is provided in Section 8.10.

- Verify that all job related data was entered in the record.
- Verify that the recorded "Fuse" interfacial pressure was within the range of qualification.
- Verify that the heater surface temperature recorded was within the range of qualification.
- The examiner shall calculate the fusion pressure for the fusion machine and add the drag pressure to confirm the machine's hydraulic fusion gauge pressure. This fusion gauge pressure must be shown in the recorded pressure/time diagram at the initial heater contact and during the fusion/cool cycle.
- Verify that the fusion gauge pressure dropped quickly to a value less than or equal to the drag pressure at the beginning of the heat soak cycle.
- At the end of the heat soak cycle, review that the machine was opened, the heater removed and the pipe ends brought together at the fusion gauge pressure as quickly as possible (not to exceed allowance in procedure).

Verify that the machine fusion gauge pressure was within the range of qualification for the pipe diameter being fused. Observe that the data recording device stopped logging at the end of the fusion/cool cycle.

### 8.6.2 Types of Mechanical Tests Required for Qualification

A. High Speed Tensile Impact Test

1) Significance and Use

This test method is designed to impart tensile impact energy to a butt fused plastic pipe specimen. The failure mode is used as criterion in the evaluation of the butt fusion joint.

2) Test Specimens

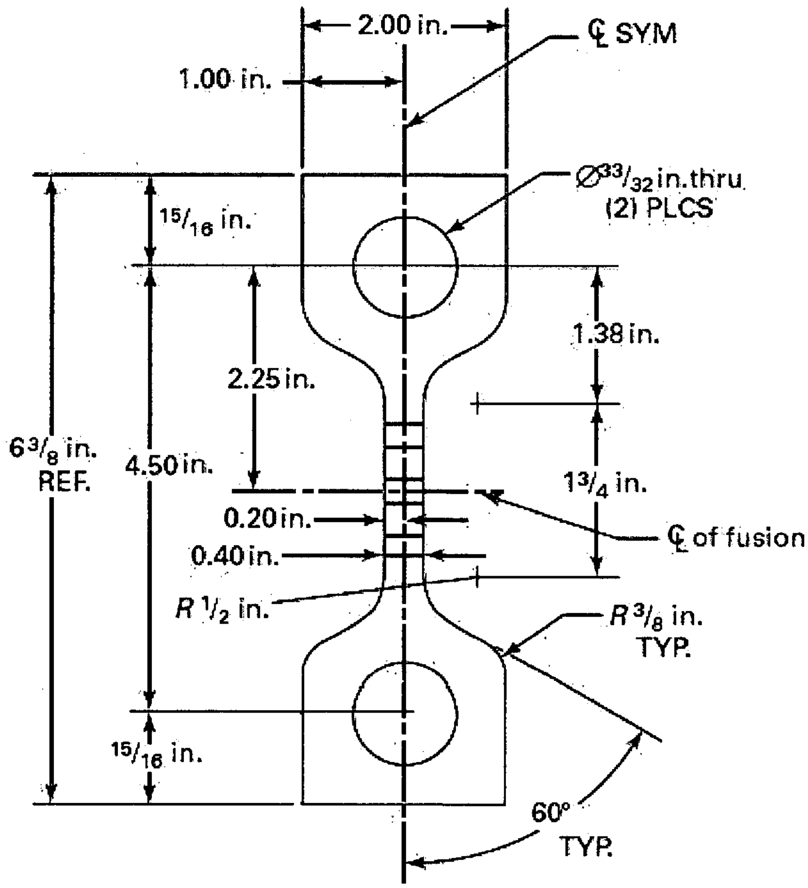
The test specimen shall conform to the dimensions shown in Figure 8-4. Test specimens of butt fused pipe shall have the bead remain on the outside and inside. Test specimens of butt fused pipe shall use the full wall thickness.

Test specimens shall be prepared by machining operations on butt fused sections of pipe and on the pipe itself. The machining operations shall result in a smooth surface on both sides of the reduced area with no notches or gouges.

All surfaces of the specimen shall be free of visible flaws, scratches, or imperfections. Marks left by coarse machining operations shall be carefully removed with a fine file or abrasive, and the filed surfaces shall then be smoothed with abrasive paper (600 grit or finer). The finishing sanding strokes shall be made in a direction parallel to the longitudinal axis of the test specimen. In machining a specimen, undercuts that would exceed the dimensional tolerances shall be avoided.

When marking the specimens, use a permanent marker of a color that will be easily read or etch the specimen number in the area outside the hole.

Figure 8-4: Tensile Full Thickness Impact Test Coupon Configuration




General Note: All machined surfaces 125 RMS or better.

3) Number of Test Specimens – The following specifies the number of required test specimens:

   *(a)* Four test specimens shall be cut 90 degrees apart from a pipe coupon made of pipe sizes larger than 4 inches.
   *(b)* Two test specimens shall be cut 180 degrees apart from a pipe coupon made from 2 inch to 4 inch pipe sizes.
   *(c)* For pipe sizes with a wall thickness greater than 2.5 inches, the test specimen shall be cut into equal thicknesses to fit the test machine.

4) The speed of testing is in accordance with Table 8-1.

Table 8-1: Testing Speed

| Wall Thickness | Testing Speed |
|---|---|
| ≤ 1.25 in. | 6 in/s |
| > 1.25 in | 4 in/s |

General Note: Testing speed tolerance: + 5 in./s to − 1 in./s

5) Conditioning

Condition the test specimens at 73.4°F ± 4°F for not less than one hour prior to test.

Conduct the tests at 73.4°F ± 4°F unless otherwise specified by contract or the relevant ASTM material specification.

6) Test Procedure

Set up the machine and set the speed of testing to the proper rate as required in Section 8.6.2.

Pin each specimen in the clevis tooling of the testing machine. This will align the long axis of the specimen and the tooling with the direction of pull of the machine.

Determine the mode of failure and note in the report.

7) Acceptance Criteria

The failure mode shall not be brittle in the Fusion Interface under the graph produced, Force vs. Time, as per ASTM F2634-07 Figures X1.1 and A1.2, not as per Figure X1.3

B. Elevated Temperature Sustained Pressure Tests

The following provides the requirements for the test specimens:

1) Test specimens shall be made from a minimum of two pieces of pipe with the completed specimens having at least five times the pipe OD on each side of the fusion joint. The minimum pipe size used shall be IPS 8 DR11.
2) Test performance shall be in accordance with ASTM D 3035-06.

C. Free Bend Tests

1) For pipes with a wall thickness less than or equal to 1 inch, two bend specimens shall be removed from the joint approximately 180° apart.
2) One test specimen shall be bent so that the inside surface of the joint is in tension and the other shall be bent so that the outside surface of the joint is in tension. The ends of each specimen shall be brought together until the ends of the specimens touch.
3) The specimens shall not crack or fracture in the fused joint.

Figure 8-5: Bend Specimen

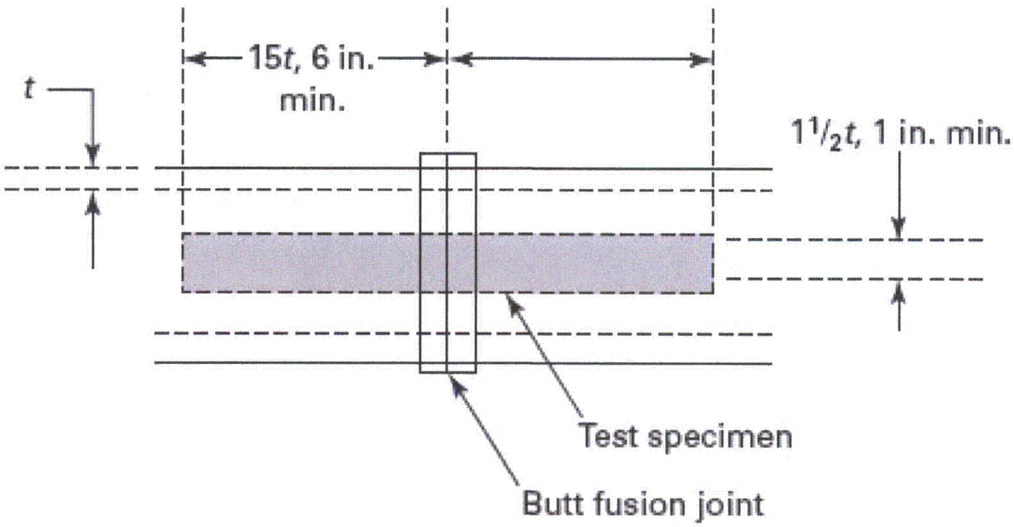
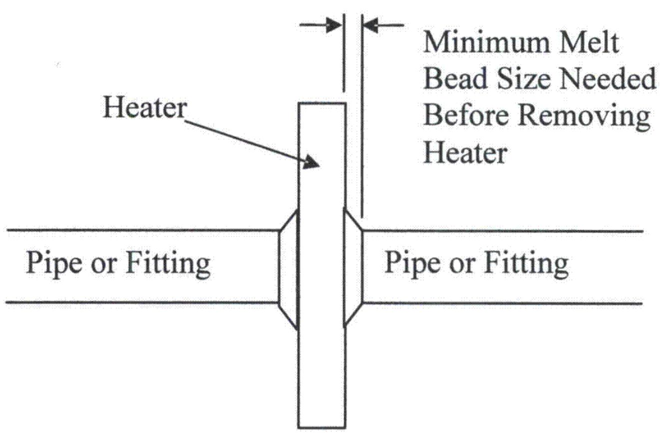



Figure 8-6: Minimum Melt Bead Size



## 8.7 Fusion Procedure Qualifications

### 8.7.1 General

Each manufacturer or contractor shall prepare Fusion Procedure Specifications (FPS) that are defined as follows:

A. A FPS is a written qualified fusing procedure prepared to provide direction for making production fused joints to the requirements of this TR.

B. The completed FPS describes all essential variables for the fusion process used in the FPS. The essential variables are listed in Section 8.6.1. The manufacturer or contractor may include any other information in the FPS that may be helpful in making a fused joint.

C. Changes in essential variables require re-qualification of the FPS.

D. The information required to be in the FPS may be in any format, written or tabular, to fit the needs of each manufacturer or contractor, as long as Form TR-2 has been provided as a guide for the FPS. This Form includes the required data for the fusion process and is located in Appendix A.

E. The FPS used for production fusing shall be available for reference and review by the Authorized Nuclear Inspector at the fabrication or installation site.

### 8.7.2 Manufacturer's Responsibility

A. Each manufacturer or contractor shall list the parameters applicable to fusing that he performs in construction of fusion joints made in accordance with this TR. These parameters shall be listed in the FPS.

B. Each manufacturer or contractor shall qualify the FPS by the fusing of test coupons, testing of specimens cut from the test coupons, and recording fusing data and test results in the Procedure Qualification Record (PQR). The fusion machine operators used to produce the fused joints to be tested for qualification of procedures shall be under the full supervision and control of the manufacturer or contractor during the production of these test fused joints. The fused joints to be tested for qualification of procedures shall be fused either by direct employees or by individuals engaged by contract for their services as fusion machine operators under the full supervision and control of the manufacturer or contractor. It is not permissible for the manufacturer or contractor to have the supervision and control of fusing of the test fused joints performed by another organization. It is permissible, however, to subcontract any or all of the work of preparation of test material for fusing and subsequent work on preparation of test specimens from the completed fused joint, performance of nondestructive examination, and mechanical tests, provided the manufacturer or contractor accepts the responsibility for any such work.

C. This Topical Report recognizes a manufacturer or contractor as the organization which has responsible operational control of the production of the fusion joints. If in an organization effective operational control of fusing procedure qualification for two or more companies of different names exists, the companies involved shall describe in their Quality Control System/Quality Assurance Program and the operational control of procedure qualifications. In this case separate fusion procedure qualifications are not required, provided all other requirements of this Section are met.

D. Except as noted in Section 8.7.3.(A).(1), the manufacturer or contractor shall certify that he has qualified each FPS, performed the procedure qualification tests, and documented it with the necessary Procedure Qualification.

8.7.3 Fusion Procedure Specifications

Butt fusion requirements, including process controls, are described in Sections 8.6 thru 8.10. PPI TR-33 and ASTM F2620, were used as the basis for developing butt fusion requirements.

A. Standard Fusion Procedure Specification

B. When the FPS is limited to the following parameters, qualification testing is not required. If the manufacturer or contractor deviates from the conditions listed below, procedure qualification testing specified in Sections 8.6.2, 8.7.3.D, and 8.7.4 is performed.

1) The pipe is limited to the horizontal position, ±45°.

2) Pipe ends are faced to establish clean, parallel mating surfaces that are perpendicular to the pipe centerline on each pipe end. When the ends are brought together, there shall be no visible gap.

3) The outside diameters of piping components to be fused shall be aligned as accurately as practical within existing commercial tolerances on diameters, wall thicknesses, and out of roundness. Alignment shall be preserved during fusion. The external misalignment of the ends to be joined shall not exceed 1/16". A gauge will be used to verify that this tolerance is met. The fusion machine which grips the pipe shall be adjusted vertically to ensure the centerlines of each pipe are parallel to each other within the 1/16" tolerance.

4) The drag pressure will be measured and recorded. The fusion pressure will be calculated so that an interfacial pressure of 60 to 90psig is applied to the pipe ends.

5) The heater plate surface temperature shall be 400°F to 450°F measured at four locations approximately 90° apart on both sides immediately prior to insertion of the heater plate in the fusion machine.

6) The heater plate shall be inserted into the gap between the pipe ends and fusion pressure shall be applied and maintained until an indication of melt is observed around the circumference of the pipe. The pressure shall be reduced to drag pressure and the fixture shall be locked in position so that no outside force is applied to the joint during the soak time.

7) The ends will be held in place until the following bead size, shown in Table 8-2 is formed during the heat soak cycle between the heater faces and the pipe ends.

Table 8-2: Approximate Melt

| Pipe Size, (Diameter), in. | Bead Size, in. |
|---|---|
| < 3 IPS | 1/16 |
| ≥ 3 IPS to ≤ 8 IPS | 3/16 |
| > 8 IPS to ≤ 12 IPS | 1/4 |
| > 12 IPS to ≤ 24 IPS | 3/8 |
| > 24 IPS to ≤ 36 IPS | 7/16 |
| > 36 IPS to ≤ 54 IPS | 9/16 |

8) After the proper bead size is formed, the machine will be opened and the heater removed. The pipe ends will be brought together and the fusion pressure reapplied.

9) The maximum time from removal of the heating plate until the pipe ends are pushed together shall not exceed the times given in Table 8-3.

Table 8-3: Maximum Removal Time

| Pipe Wall Thickness, in. | Max. Heater Plate Removal Time |
|---|---|
| 0.20 to 0.36 | 8 sec |
| > 0.36 to 0.55 | 10 sec |
| > 0.55 to 1.18 | 15 sec |
| > 1.18 to 2.5 | 20 sec |
| > 2.5 to 4.5 | 25 sec |
| Material Manufacturer Facility | |
| > 1.18 to 2.5 | 40 sec |
| > 2.5 to 4.5 | 50 sec |

10) The fusion pressure is maintained until the joint has cooled after which the pipe can be removed from the fusion machine. The cooling time under pressure shall be 30 to 90 seconds per inch of pipe diameter. When the wall thickness is greater than 2 inches, use 90 seconds per inch of pipe diameter for the cooling time.

C. Essential Variables for Fusion Procedure Specification (FPS)

Any change in essential variable listed in Section 8.6.1.A, requires requalification of the FPS.

D. Testing Procedure to Qualify the FPS

1) Use 8 in. IPS DR11 pipe size as a minimum for the qualification test of butt fusion joints.

2) Make the following butt fusion joints using the following combinations of heater temperature ranges and interfacial pressure ranges and the FPS:

- High heater surface temperature and high interfacial pressure, five joints.
- High heater surface temperature and low interfacial pressure, five joints.
- Low heater surface temperature and high interfacial pressure, five joints.
- Low heater surface temperature and low interfacial pressure, five joints.

3) Evaluate three joints of each combination using the High Speed Tensile impact tests per Section 8.6.2. All joints must fail in a ductile mode.

4) Evaluate two joints of each combination using the Sustained Pressure Testing per Section 8.6.2.B. All joints must pass this test.

8.7.4 Mechanical Tests

A. General Requirements

1) The type and number of test specimens that shall be tested to qualify an FPS for a butt fusion joint are given in Section 8.7.3.D. If any test specimen required by Section 8.7.3.D fails to meet the applicable acceptance criteria, the test coupon shall be considered as failed.

2) When it can be determined that the cause of failure is not related to fusing parameters, another test coupon may be fused using identical fusing parameters.

3) Alternatively, if adequate material of the original test coupon exists, additional test specimens may be removed as close as practical to the original specimen location to replace the failed test specimens.

4) When it has been determined that the test failure was caused by an essential variable, a new test coupon may be fused with appropriate changes to the variable(s) that was determined to cause the test failure.

5) When it is determined that the test failure was caused by one or more fusing conditions other than essential variables, a new set of test coupons may be fused with the appropriate changes to the fusing conditions that were determined to cause the test failure. If the new test passes, the fusing conditions that were determined to cause the previous test failure shall be addressed by the manufacturer to ensure that the required properties are achieved in the production fused joint.

B. Preparation of Test Coupon

The base materials shall consist of PE 4710 pipe. The dimensions of the test coupon shall be sufficient to provide the required test specimens.

8.7.5 Fusion Machine Qualification

Each fusion machine is tested to determine its ability to make fused joints consistently and reproducibly. A machine will be re-qualified whenever it is rebuilt, moved to a new location requiring a change in power supply, when the power supply is changed, or any other significant change is made to the equipment. Fusion machine qualification testing shall consist of making a set of 100 consecutive fused joints. Every fifth joint shall be subjected to test given in Section 8.7.3.C. Five joints, which shall include one of the first five and one of the last five of the set, shall be examined. Testing and acceptance criteria for fusion machine qualification is in accordance with Section 8.6.2.

8.8 Fusion Performance Qualification

8.8.1 This Section lists the essential variables that apply to fusion machine operator performance qualifications.

A. Scope

The basic premises of responsibility in regard to fusion are contained within Sections 8.6.A and 8.8.1.C. These paragraphs require that each manufacturer or contractor (an assembler or an installer) shall be responsible for conducting tests to qualify fusion machine operators. This qualification is in accordance with qualified Fusion Procedure Specifications, which their organization employs in the construction of fused joints. The purpose of this requirement is to ensure that the manufacturer or contractor has determined that the fusion machine operators using the applicable procedures are capable of developing the minimum requirements specified for an acceptable fused joint. This responsibility cannot be delegated to another organization.

The fusion machine operators used to produce such fused joints shall be tested under the full supervision and control of the manufacturer or contractor during the production of these test fused joints. It is permissible to subcontract any or all of the work of preparation of test materials for fusing and subsequent work on the preparation of test specimens from the completed fused joints, performance of nondestructive examination and mechanical tests, provided the manufacturer, contractor, assembler, or installer accepts full responsibility for any such work.

Manufacturers or contractors may maintain effective operational control of fusion machine operator performance qualification (FPQ) records under different ownership than existed during the original fusion machine operator qualification. When a manufacturer or contractor or part of a manufacturer or contractor is acquired by a new owner(s), the FPQ may be used by the new owner(s) without re-qualification, provided all of the following are met:

1) New owner(s) takes responsibility for the FPQ
2) FPQ reflects the name of the new owner(s), and
3) Quality Control System/Quality Assurance Program reflects the source of the FPQ as being from the former manufacturer or contractor.

B. More than one manufacturer or contractor may simultaneously qualify one or more fusion machine operators. When simultaneous qualifications are conducted, each participating organization shall be represented during fusing of test coupons by an employee who is responsible for fusion machine operator performance qualification.

1) The FPSs that are followed during simultaneous qualifications shall be compared by the participating organizations. The FPSs shall be identical for all essential variables. The qualified thickness ranges for base material need not be identical, but these thicknesses shall be adequate to permit fusing of the test coupons. Alternatively, the participating organizations shall agree upon the use of a single FPS provided each participating organization has a FPS covering the range of essential variables to be followed in the performance qualification. When a single FPS is to be followed each participating organization shall review and accept that FPS.
2) Each participating organization's representative shall positively identify each fusion machine operator who is being tested. Each organizational representative shall also verify marking of the test coupon with the fusion machine operator's identification.
3) Each organization's representative shall perform a visual examination of each completed test coupon and shall examine each test specimen to determine its acceptability. Alternatively, after visual examination, when the test coupon(s) are prepared and tested by an independent laboratory, that laboratory report may be used as the basis for accepting the test results.
4) Each organizational representative shall complete and sign a fusion machine operator FPQ record for each fusion machine operator. Data Report Form TR-2 has been provided as a guide for the FPS.
5) When a fusion machine operator changes employers between participating organizations, the employing organization shall verify that the fusion machine operator's continuity of qualifications has been maintained (as required by Section 8.8.3B by previous employers) since his qualification date. If the fusion machine operator has had his qualification withdrawn for specific reasons, the employing organization shall notify all other participating organizations that the fusion machine operator's qualification(s) has been revoked in accordance with Section 8.8.4.A. The remaining participating organizations shall determine that the fusion machine operator can perform satisfactory work.

6) When a fusion machine operator's qualifications are renewed in accordance with the provisions of Section 8.8.3.C, each renewing organization shall be represented by an employee who is responsible for fusion machine operator performance qualification. The testing procedures shall follow the rules of this paragraph.

C. Tests

1) The performance qualification tests are intended to determine the ability of fusion machine operators to make sound fused joints.

2) Each manufacturer or contractor shall qualify each fusion machine operator for the fusing process to be used in production. The performance qualification test shall be fused in accordance with a qualified FPS. Changes beyond which re-qualification is required are given in Section 8.8.3.B. Allowable visual and mechanical examination requirements are described in Section 8.8.1.E. Retests and renewal of qualification are given in Section 8.8.3.

The fusion machine operator who prepares the FPS qualification test coupons meeting the requirements of Section 8.7 is also qualified within the limits of the performance qualifications, listed in Section 8.8.1.E for fusion machine operators.

3) The record of fusion machine operator FPQ tests shall include the essential variables, the type of test and test results, and the ranges qualified in accordance with Data Report Form TR-3 for each fusion machine operator.

D. Type of Test Required

1) All Mechanical tests shall meet the requirements prescribed in Section 8.6.2.C.

2) Test butt fusion test coupons shall be fused as shown in Figure 8-3. The test specimens shall be removed from the test butt fusion joint in accordance with Figure 8-5.

3) For pipe coupons all surfaces shall be examined visually per Section 8.3.1 before cutting of bend specimens. Pipe coupons shall be visually examined per Section 8.3.1 over the entire circumference, inside and outside. The examination shall evaluate the base material at least two inches from each side of the joint.

E. Fusion Machine Operators

Each fusion machine operator who fuses under the rules of this section shall have passed the mechanical and visual examinations prescribed in Section 8.8.1.D.

F. Fused joints made in test coupons for performance qualification shall be examined by mechanical and visual examinations (See Section 8.8.1.D).

8.8.2 Qualification Test Coupons

A. The test coupons shall be pipe. Qualifications for pipe are accomplished by fusing one pipe assembly in the horizontal axis position (Figure 8-3, Horizontal Axis Position). The minimum pipe size shall be IPS 6.

8.8.3 Retests and Renewal of Qualification

A. Retests

A fusion machine operator who fails one or more of the tests prescribed in Section 8.8.1.E, as applicable, may be retested under the following conditions:

1) When the qualification coupon has failed the visual examination of Section 8.8.1.D, retesting shall be by visual examination before conducting the mechanical testing.

When an immediate retest is made, the fusion machine operator shall make two consecutive test coupons all of which shall pass the visual examination requirements.

The examiner may select one of the successful test coupons from each set of retest coupons which pass the visual examination for conducting the mechanical testing.

2) When the qualification coupon has failed the mechanical testing of Section 8.8.1.D, the retesting shall be mechanical testing.

When an immediate retest is made, the fusion machine operator shall make two consecutive test coupons which shall pass the test requirements.

3) When the fusion machine operator has had further training or practice, a new test shall be made.

B. Expiration and Renewal of Qualification

The performance qualification of a fusion machine operator shall be affected when one of the following conditions occurs:

1) When they have not fused with a process during a period of six months or more, their qualification for that process shall expire.

2) Any fusion machine operator who makes a fusion joint that fails hydrostatic test will immediately lose their qualifications for fusion and be required to repeat the training course as well as be re-qualified.

3) When there is a specific reason to question an operator's ability to make fused joints that meet the specification, the qualifications that support the fusing being performed shall be revoked.

C. Renewal of Qualification

1) Renewal of qualification expired under 8.8.3.B may be made by fusing a single test coupon and by testing of that coupon as required by Section

8.8.1.C. A successful test renews the fusion machine operator's previous qualifications for the process for which he was previously qualified.

2) Fusion machine operators whose qualifications have been revoked under Section 8.8.3.B above shall re-qualify. Qualification shall utilize a test coupon appropriate to the planned production work. The coupon shall be fused and tested as required by Section 8.8.1.C and 8.8.1.D. Successful test restores the qualification.

8.8.4 Fusion Variables for Fusion Machine Operators

A. General

A fusion machine operator shall be re-qualified whenever a change is made in one or more of the fusion machine variables.

1) A change in pipe diameter from one range to another;

*(1)* Less than IPS 8"
*(2)* IPS 8" to IPS 24"
*(3)* IPS over 24"

2) A change in name of the manufacturer of equipment

3) The axis of the pipe is limited beyond the horizontal position ±45°. Qualification in any position other than horizontal qualifies the orientation tested ± 20°.

8.8.5 Testing

A. Test joints shall be IPS 8" DR11 for testing at a minimum. A data acquisition recorder shall be attached to the fusion machine and the data concerning the joint entered. The data acquisition device shall be used to record data required by Section 8.6.1.A.

B. The supervisor conducting the test shall observe making of the butt fusion joint and note if the FPS was followed.

C. The completed joint shall be visually examined and meet the acceptance criteria of Section 8.3.1

D. After the joint is complete the data acquisition record shall be reviewed by the assessor and compared to the FPS to ensure the proper procedures were followed.

E. The test specimens shall be removed, tested and meet the acceptance criteria in accordance with Section 8.6.2.C.

## 8.9 Fusion Machine Operator Qualification Training

It is important that the fusion machine operators are trained and competent in the fusion technology employed in constructing PE piping systems. Continued competence of the fusion operator is covered by periodic retraining and reassessment.

This section provides guidance for the training, assessment and approval of fusion machine operators. This section covers both the theoretical and practical knowledge necessary to ensure high quality fusion joints.

### 8.9.1 Training Course

A. A trainee fusion operator for PE systems will complete a training course in order to obtain a fusion operator certificate. The course will cover all aspects of the butt fusion process including safety, machine evaluation and maintenance, machine operation, FPS guidelines, pressure and temperature setting, data log device operation and set-up, visual examination guidance, and data log record evaluation. The minimum course duration is 24 hours.

B. The course will be delivered by a competent qualified trainer with a minimum of three years of experience in the butt fusion processes and who has mastered the techniques involved.

C. The trainer should have a range of fusion machines representative of the equipment encountered on worksites for installing pipes, in order for the trainee fusion operator to become acquainted with the fusion equipment commonly used. The trainee fusion operator may be trained on one of these fusion machines or on a machine from the parent company. The fusion equipment must comply with the fusion machine manufacturer's specifications and/or ISO 12176-1 "Plastics Pipes and Fittings – Equipment for Fusion Jointing Polyethylene Systems – Part 1: Butt Fusion."

### 8.9.2 Operator Assessment

The trainee fusion operator who has completed a training course as described above will then pass a theoretical and practical assessment in order to be qualified as a fusion operator for PE systems. The assessor should not be the trainer, but should have the same assessment qualifications as the trainer.

### 8.9.3 Training Curriculum

A. The training course should comprise of any combination of fusion packages based on the requirements of utility or pipeline operators. These packages may be given as individual modules or combined to suit requirements.

B. The pipes and fittings to be used shall conform to the ASTM product forms permitted by this Topical Report.

C. The lessons will be designed so that the trainee fusion operator learns to master the fusion technique and attains a good working knowledge of the piping system materials and practical problems encountered when fusing pipe in the field. The fusion operator will receive a written manual covering the elements contained in the training.

D. The theoretical course will include general information pertaining to raw materials, pipes and fittings, and will also include knowledge about preparation, tools, and devices, joining components, different materials, different diameter ratios and correct and incorrect parameters. The safety course will include information concerning the fusion process, such as protective clothing, general safety, regulations for electrical equipment, handling heater plates, etc. Areas of study will include the following:

1) Butt fusion joining.
   - Principles of fusion.
   - Straight/coiled pipes, service lines, main lines, etc.
   - Components: pipes, flange adapters saddle fittings, other fittings.
   - Butt fusion equipment: manual, semi-automatic and automatic machines.
   - Joint preparation: cleaning, rounding, alignment, facing, etc.
   - Butt fusion cycle: pressure, time and temperature relationships, diagram.
   - Failure modes: understanding and avoiding possible errors.
   - Test methods: visual examination, high speed tensile-impact test, bending test, hydrostatic test, data log recording/evaluation, etc.
2) The trainee fusion operator should be familiar with the butt fusion joining technique and procedure by making a sufficient number of butt fusion joints. In some cases, the fusion technique may vary slightly according to diameter, material or other factors. In such cases, the trainee fusion operator should also be made familiar with the various techniques.
3) The trainee should start by making a butt joint between two pipes, and should then learn to make butt fusion joints with pipes and fittings such as tees, reducers, etc.

4) The trainee should learn how to detect and avoid typical fusion defects.

5) The trainee should learn how to assess the quality of a butt fusion joint by doing a visual examination of the butt fusion joint and comparing it to the visual guidelines published in the pipe manufacturer's heat fusion joining procedure booklet. The trainee should also compare the data log record to the FPS to ensure the proper parameters and procedures were followed in the butt fusion process.

8.9.4 Assessment and Testing

A. Training program will end with a theoretical and practical examination.

B. The content of the theoretical examination shall consist of not less than twenty multiple choice questions about the butt fusion process, fusion machine operation, pipe, quality examination, safety, etc. within a set period of time. A score of 80% or better is considered passing on this examination. Questions to be included, but not limited to, are:

- How do you calculate the fusion machine gauge pressure?
- What is the proper heater surface temperature range from the FPS?
- What is the proper butt fusion interfacial pressure range from the FPS?
- How is drag pressure calculated?
- When is the heater to be removed during the heating cycle?
- How long are the pipe ends to remain together under pressure in the cooling cycle?
- What is the difference between IPS pipe and DIPS pipe?
- How is the hydraulic fusion machines total effective piston area determined?
- How is the total effective piston area of the fusion machine used to determine the fusion machines gauge pressure for a specific pipe?
- How can the machine be adjusted to improve the alignment of the pipe after facing?
- How much material should be removed from the pipe ends in the facing operation?
- Does the fusion machine conform to the equipment manufacturer's specifications?
- How is the pipe to be aligned in the butt fusion machine?
- What is interfacial pressure?

C. The practical examination will require the trainee to make a fusion joint with a hydraulic butt fusion machine with a minimum pipe size of 6 in. IPS DR11. A data acquisition device must be attached to the fusion machine and the data concerning the joint entered. The data log device shall be used to record the joint made by the trainee. The assessor shall observe the butt fusion joint and note if the proper procedure was followed. After the joint is complete, the data log record shall be reviewed by the assessor and compared to the FPS to ensure the proper procedures was followed. The assessor will then conduct a visual examination of the joint to make sure it satisfies the pipe manufacturers recommended visual guidance criteria.

D. If a data log device is not available, the assessor will manually record the butt fusion parameters used in the butt fusion process. This will be compared with the FPS to ensure they agree.

E. Trainee fusion operators who pass the theoretical and practical examination receive a fusion operator certificate bearing the logo of the assessment center awarding the approval. The fusion operator certificate will state the technique and fusion machines for which the operator is qualified.

8.9.5 Reassessment

If the trainee fails one of the examinations, a re-examination will be available after a period not shorter than one week. If the trainee fails the examination for the second time, the trainee should repeat the training course before taking the test again.

8.10 Data Acquisition Log Review

Review both the recorded log information and the pressure/time graph to evaluate if the proper procedure was followed. The following examples are shown to assist in this evaluation:

8.10.1 Recorded Data Log Information Correct Procedure. All job information must be entered. All essential variables listed in Section 8.6.1.A.1 shall be documented on the Recorded Data Log. All essential variables must be within the qualified range.

8.10.2 Pressure/Time Graph Evaluation. No Errors (see Figure 8-7, Typical Time/Pressure Diagram of a Butt Fusion Weld).

A. P1: Drag Pressure. Fusion machine mechanical drag plus pipe drag. Pressure may drop to 0psi during soak cycle (psi gauge).

B. P2: Fusing Pressure. Calculated machine fusion gauge pressure plus drag pressure.

C. T1: Initial Heater Contact Time at Fusion Pressure. Time required to observe an indication of melt around the pipe circumference.

D. T2: Heat Soak Time. Time required to develop the size of melt bead against the heater specified in the procedure.

E. T3: Heater Removal Time. Time required to open the fusion machine, remove the heater and bring the pipe ends together at fusion pressure. The time must not exceed the time in the specification.

F. T4: Cool Time. Time required to cool the joint at fusion gauge pressure. This must be 30–90 seconds per inch of pipe diameter. Use 90 seconds per inch of pipe diameter for any pipe diameter with a wall thickness greater than 1.50 in.

8.10.3 Correct Procedure. The following requirements apply (see Figure 8-8, Correct Procedure):

A. Review if P1 and P2 recorded gauge pressures agree with the specified fusion procedure. P2 can drop to zero during the heat soak cycle.

B. Review if P2 is maintained for 30–90 seconds per inch of pipe diameter during the fuse/cool cycle.

C. On large diameter heavy wall pipe it sometimes takes several minutes to see an indication of melt around the circumference of the pipe, so the initial contact time against the heater at fusion gauge pressure is usually longer than normal. Make sure the heat soak time is longer than the initial contact time.

Figure 8-7: Typical Time/Pressure Diagram of a Butt Fusion Joint

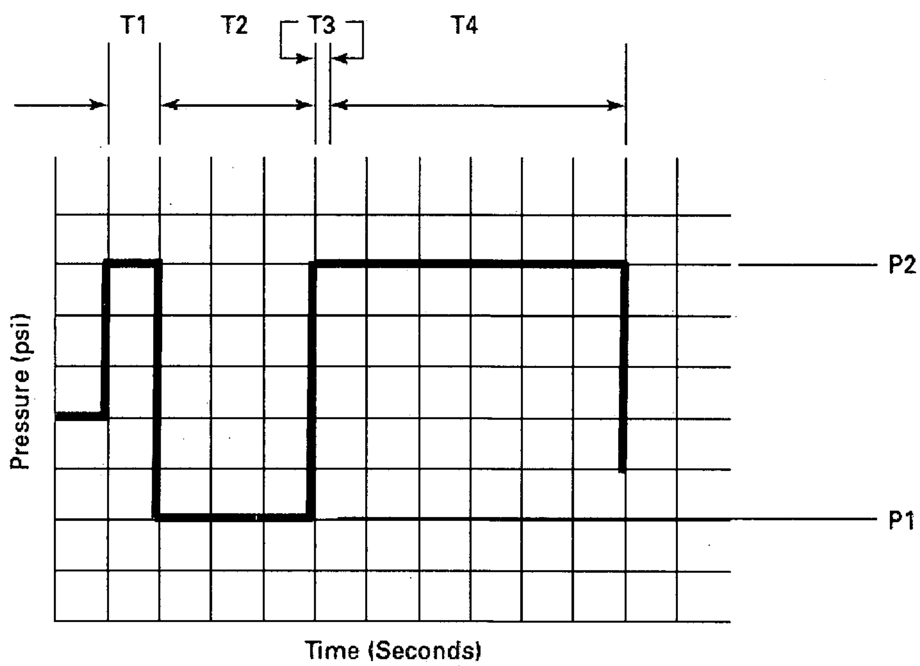


Figure 8-8: Correct Procedure

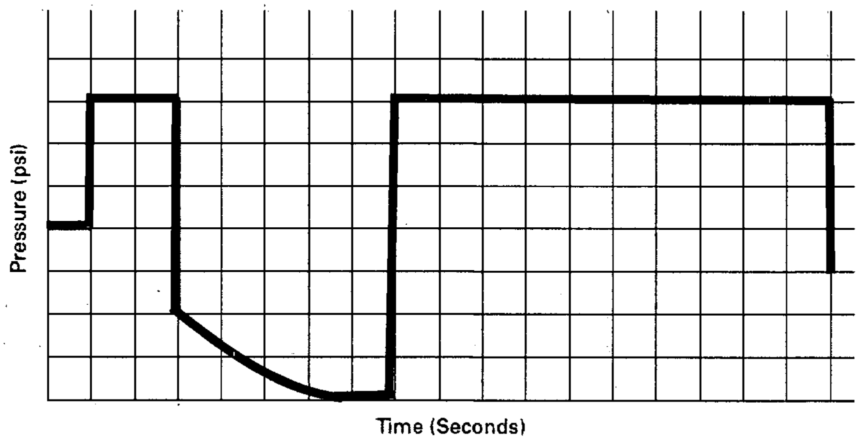
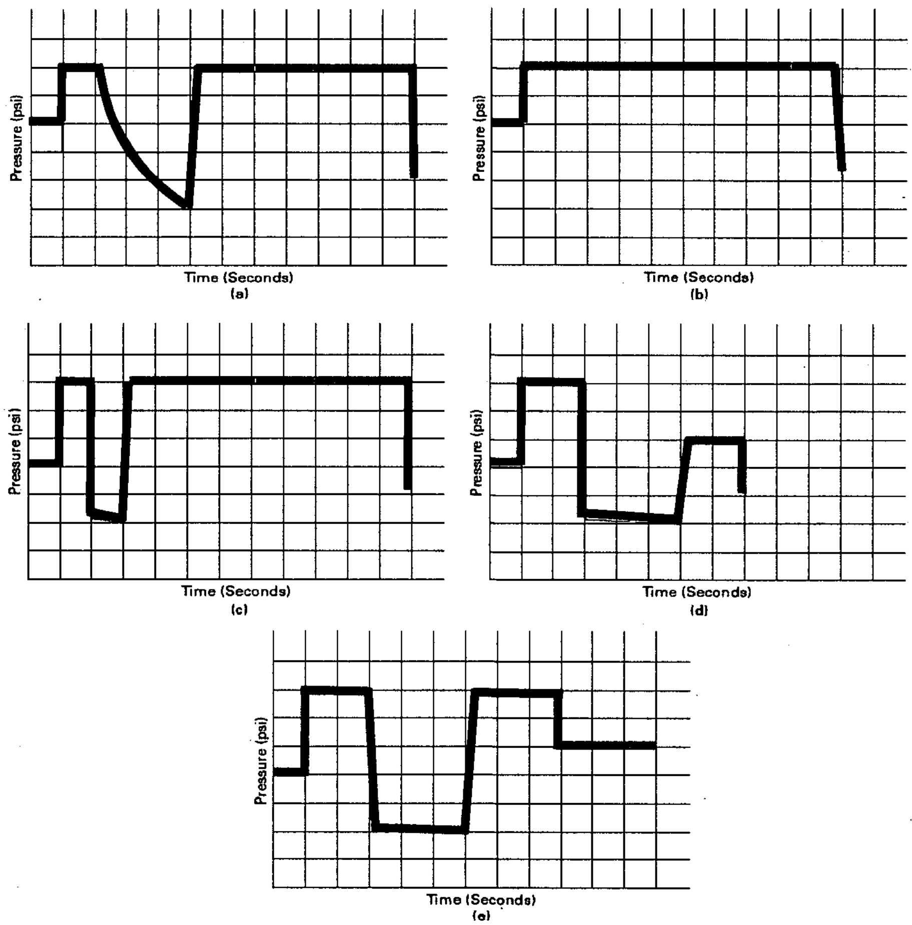



Figure 8-9: Incorrect Procedure



8.10.4 General Notes:

A. No Heat Soak Time: Pressure not reduced at start of Heat Cycle.

B. No Heat Soak Time: Pressure maintained during Heat Soak Cycle.

C. Heat soak time is very short. Do a visual examination of the bead size to make sure it is within the butt fusion specifications.

D. The specified fusion gauge pressure was not applied during the Fuse/Cool cycle. The Fuse/Cool Times does not appear long enough.

E. Fusion gauge pressure not maintained in the Fuse/Cool cycle for the time in the specification.

## 8.11 HDPE ITAAC

It is proposed that ITAAC be developed to verify that as-built HDPE satisfies the design and performance standards specified in the COL. The type of information and level of detail included in the ITAAC for HDPE pipe should be based on a graded approach that is commensurate with the safety-significance of the SSCs. The ITAAC will be developed to verify HDPE design information including the principal performance characteristics, their important features in this Topical Report, and its functions for defense-in-depth.

Section C.II.1.2.3 of Regulatory Guide 1.206 provides specific guidance on ITAAC development for piping systems and components. Regulatory Guide 1.206 generically applies ITAAC to verify requirements of the ASME Code. Regulatory Guide 1.206 is used as a basis to apply the appropriate requirements of this Topical Report into ITAAC. ITAAC items that are to be incorporated, changed or applicable as currently recommended are described in the following sections. These ITAAC ensure that the HDPE piping is constructed and will operate in conformity with the design.

### 8.11.1 ITACC Revisions related to HDPE Piping

As a result of using HDPE piping in ASME Section III, Class 3 buried piping applications, several ITAAC items will be added that should reference this Topical Report.

For Class 3 piping, ITAAC are developed to verify the welding quality of as-built pressure boundary welds. Since HDPE pipe cannot be welded the way metallic pipe can, an equivalent ITAAC will be developed to demonstrate the acceptability of the butt fusion joints used to join lengths of HDPE pipe. The ITAAC shall require that pressure boundary fusion joints in the specified safety system(s) will be designed and constructed in accordance with this Topical Report. Inspections will be conducted of the as-built piping joints to assure the Topical Report requirements have been met.

It is standard to have an ITAAC to verify that components are procured, inspected, analyzed, and installed in conformance with ASME Code. Since this Topical Report contains the appropriate criteria for these processes, (including the ASME Code requirements), reference to this Topical Report will be specified for ITAAC pertaining to HDPE piping. Analysis will be performed in accordance with the Topical Report design requirements as specified in the Design Specification and compliance documented in a stress report. Piping shall be constructed and installed in accordance with the Topical Report requirements and certified in a Data Report Form. Shop and field inspections of the as-built piping will be performed by an Authorized Nuclear Inspector and certified on a Data Report Form.

An ITAAC will be added to specify that the performance, inspections and documentation of hydrostatic testing of the specified system(s) that contains HDPE piping will be in accordance with this Topical Report. Inspections of the as-built piping will be conducted to assure the Topical Report requirements have been met.

Typically, there is an ITAAC that provides for ensuring that protective measures have been applied to buried Seismic Category I pipe, such as a protective waterproof wrapping or coating. Due to the material properties of HDPE pipe, wrapping or coating is not necessary. Therefore, any existing ITAAC that address this issue, will be denoted as being applicable to only metallic pipe.

It is important that the materials used in systems that interface with brackish water are suitable for that environment. ITAAC currently specify metallic piping material in these applications, such as SA-106 Grade B carbon steel or SB-575 stainless steel. Any existing ITACC that address that issue will be revised to include the use of PE 4710 material as an additional acceptable material.

8.11.3 Applicable As-Is ITAAC for HDPE Piping

Other ITAAC requirements that are currently proposed for Class 3 piping will also apply to HDPE piping and do not require supplementing; these include: Demonstration that the piping is capable of withstanding a design basis seismic load without loss of safety function; inspections of the as-built piping to ensure the location is in accordance with the design, and; the ability to withstand design basis loads without loss of integrity.

# 9.0 DESIGN LIFE

This section demonstrates the adequacy of HDPE 4710 pipe for a 60 year service life with design conditions up to 200psig and 140°F, and with a possible short duration high temperature transient of 160°F for 30 days.

## 9.1 60 Year Design Life Determination

PE piping strength capacities vary with time when under high stresses (stresses at or close to the HDS), therefore, a design life is specified for HDPE piping systems, however, various industry standards do not limit HDPE pipe design life when the pipe wall thickness is calculated for the system design pressure and HDS is based on the system design temperature.

ASME Section III, Class 3 PE 4710 piping is sized and rated for at least 60 years of continuous operation (60 year design life) at the specified design pressures and design temperatures (between 73°F and 140°F).

ASTM and PPI standards (PPI TR-4 & ASTM D2837) list PE 4710 HDB (Hydrostatic Design Basis) values at 73°F and 140°F. These values are based on substantiation and validation (based on accelerated high temperature testing) that pipe stress rupture data confirm the 73°F regression curve is linear to 50 years and beyond (beyond the 438,000 hours intercept, see Figure 9-1, 140°F curve).

The pipe stress rupture regression curve is a linear logarithmic plot of hoop stress (Y-axis) versus time (X-axis) at a specified temperature. High stress data points have short rupture times, while low stress data points have longer rupture times.

The PPI Handbook of PE Pipe provides an equation which is used to interpolate between 73°F and 140°F to derive the HDB for intermediate temperatures.

The PE 4710 HDB at the 100,000 hours (11.4 years) intercept is multiplied by a Design Factor (DF) of 0.50 to derive the HDS (Hydrostatic Design Stress). This DF is more conservative than the DF of 0.63 listed in ASTM and PPI standards.

In addition to accounting for various manufacturing variables, use of the DF ensures that the long term maximum allowable stress (HDS) will always be significantly below LTHS at 50 years. This, together with confirmation that the 73°F regression is linear to 50 years and beyond (beyond the 438,000-hour intercept), establishes the long term maximum allowable stress (HDS).

Industry regression curves are usually only generated out to the 50 year intercept. A review of a typical 73°F linear regression curve for PE 4710 pipe shows that the LTHS at the 438,000-hour (50 years) intercept is approximately 100psi lower than the 1600psi HDB at the 100,000-hour intercept (see Section 9.4 for typical linear regression curves). Use of a Design Factor (DF) of 0.50 gives an HDS of 800psi which is 700psi lower than the 50-year LTHS.

Similarly, the 140°F PE 4710 linear regression curve shows that the LTHS at the 438,000-hour intercept of 916psi is approximately 84psi lower than the 1000psi

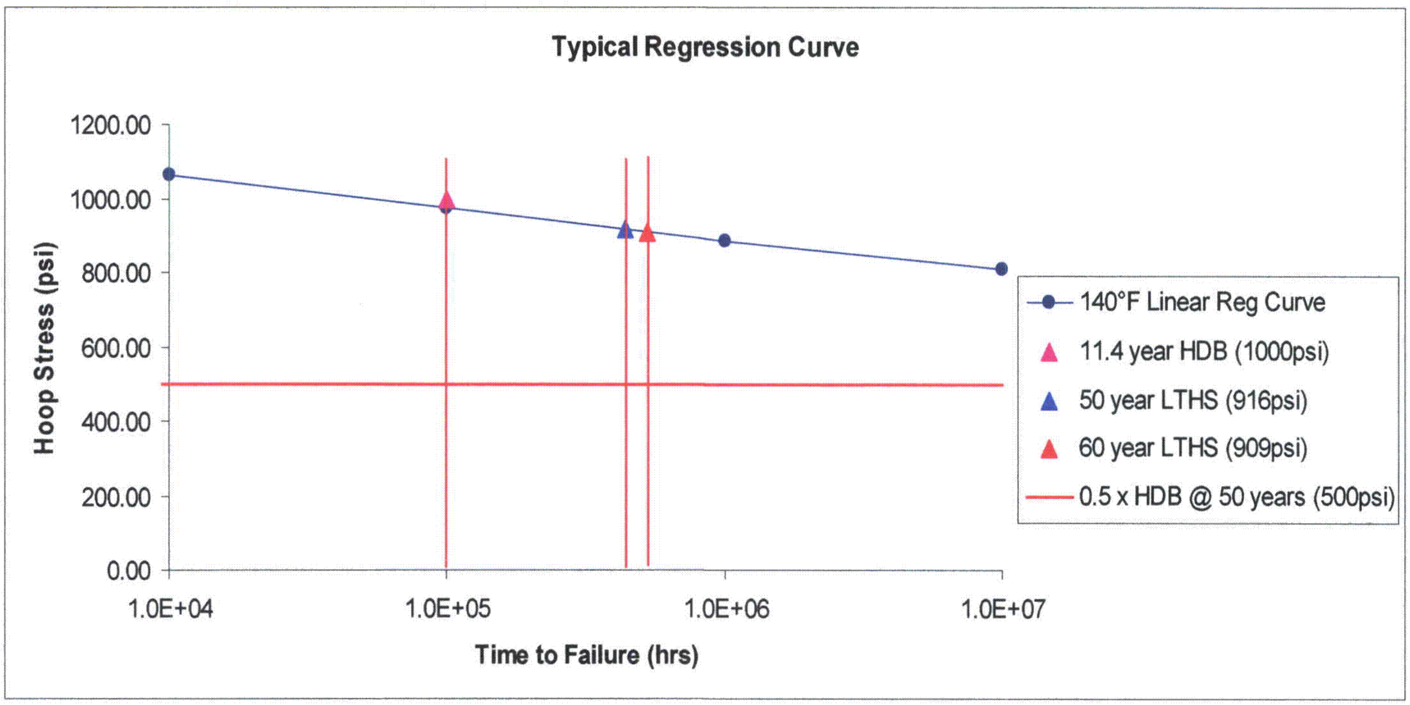
HDB at the 100,000-hour intercept. Use of a Design Factor (DF) of 0.50 gives an HDS of 500psi which is 416psi lower than the 50-year LTHS.

To determine how much lower a 60-year LTHS would be, typical PE 4710 linear regression curves for 73°F and 140°F were extrapolated beyond the 438,000-hour (50-year) intercept, to the 525,600 hours (60 years) intercept by using the three-coefficient Rate Process Method (RPM) described in Section 9.4.

It was determined that at the 60-year intercept the 73°F LTHS is 10psi lower, and the 140°F LTHS is 7psi lower, than at the 50-year LTHS intercept (see Appendix C). Similar results for a 60-year LTHS are reported in EPRI Report 1013549, Nondestructive Evaluation: Seismic Design Criteria for Polyethylene Pipe Replacement Code Case.

Below is a typical 140°F linear regression curve for PE 4710 pipe that shows its 100,000-hour intercept (indicating HDB of 1000psi). Its 438,000-hour (50-year) and 525,600 hour (60 years) intercepts are also shown. The straight horizontal line shown below it represents the 140°F HDS of 500psi (HDS = HDB x 0.5DF)

Figure 9-1: 140°F Regression Curve for PE4710




When expressed as a percent change the 60 year LTHS reduction of 10 psi is 0.6% (10psi/1600psi = 0.6% , 7psi/1000psi = 0.7%). This could be construed as a 0.6% reduction in the allowable stress, however, the allowable stress is based on the 11.4 year intercept and remains unchanged. In addition, this reduction in LTHS is more than adequately covered by the 20% margin that is provided when the pipe wall is based on a conservative design pressure, and operates under lower normal operating pressures and stresses (see Section 9.2). Additional margin is also provided by normal operating temperatures that are lower than the design temperature. These low temperatures significantly increase the LTHS for operation with the much lower normal operating pipe stresses.

In addition, this Topical Report requires a PENT rating of at least 2000hrs. As explained in Section 3.9, this high PE 4710 PENT value ensures Slow Crack Growth brittle failure will not occur for 60 plus years shown on the PE4710 regression curve. Therefore, the PE 4710 pipe can be safely designed to operate for over 60 years under normal operating conditions.

## 9.2 Minimum Wall Thickness

The HDS is the maximum allowable hoop stress for the specified temperature, and is used to calculate the required pipe minimum wall.

Conservative design pressures and design temperatures have been selected to calculate the required pipe minimum wall. These design parameters envelope maximum operating conditions that are of a very short duration and have much higher pressures and/or temperatures than the normal operating conditions. To ensure a conservative design pressure is used, it will be required that the design pressure be at least 1.20 times the normal operating pressure. In addition, the Design Temperature shall be 10°F higher than normal operating temperature.

For buried ASME Section III, Class 3 HDPE water piping, design conditions are based on maximum operating conditions that are due either to a DBA, the system's pump shutoff head, extreme ambient conditions, or combination of these events.

In assessing whether the PE 4710 pipe has been adequately designed for a 60-year service life, one must consider the duration it will operate under the high stress conditions used to select its pipe wall thickness. During normal operating conditions, the selected pipe wall will be subjected to a much lower stress.

It is possible that an industry standard pipe wall will be selected (DR6, DR7, DR9, DR 11, etc.) that results in a hoop stress exactly equal to the PE 4710 HDS under design conditions, however, the calculated pipe minimum wall is usually slightly less than the standard wall selected and the pipe stress under design conditions is usually slightly lower than the HDS for the design temperature. With the selected pipe wall one can operate continuously under design conditions for the 60-year service life. If design conditions occur for no more than one month during the 60-year life of the plant (0.14% of the time) then normal operating conditions will exist 99.86% of the time.

With the pipe wall selected for design conditions, the pipe stress under normal operating conditions will be at least 25% less than the HDS for the normal operating temperature. Under these lower stress conditions the pipe has a much longer design life than the 60 year service life.

To demonstrate this, the three coefficient Rate Process Method (RPM) equation given in ASTM D 2837 Paragraph 5.6.1.2 (and described in PPI TN-16/2008) with coefficients derived from the typical PE 4710 linear regression curves noted in

Section 9.1, is used to calculate the time to rupture for various typical "low stress / low temperature" normal operating conditions (LTHS used in RPM equation equals two times the normal operating pipe stress).

Given the design margins noted above for the Design Temperature and Pressure, in all cases with typical normal operating conditions the time to failure exceeds 1000 years (See methodology described in Appendix C).

9.3 Corrosion Allowance

No corrosion allowance is considered in the minimum wall thickness calculation used to select the pipe wall. HDPE will not rust, rot, pit, corrode, tuberculate or support biological growth.

A major advantage of HDPE is its virtual freedom from attack by soils, and by ambient water and moisture. PE, being a non-conductor of electricity, is immune to the electrochemical based corrosion process that is induced by electrolytes such as salts, acids and bases. In addition, PE piping is not vulnerable to biological attack, and its smooth, non-stick inner surface results in low friction factors and exceptional resistance to microbiological influenced corrosion.

The biocides used will be similar to those successfully used in chlorinated potable water HDPE piping systems. As noted in Jana Laboratories Technical Report "Long-Term Performance of PE Piping Materials in Potable Water Applications," dated 9/17/2009, and listed in the PPI listing of "Municipal / Industrial Publications;" with HDPE piping the chlorinated water oxidative process can take many hundreds, even thousands, of years to occur.

The Jana report has projected HDPE piping performance based on accelerated laboratory testing per ASTM F2263, using the Rate Process Method for various elevated temperatures and pressures, and potable water qualities, and found that PE4710 pipe will have a potable water design life well beyond 100 years.

When burying pipe, clean bedding and back fill will be used to shield it from contaminated soil. Therefore, no corrosion allowance is required.

9.4 Design for Elevated Temperatures

In unusual circumstances, design conditions that occur for no more than one month during the 60 year plant life may require operation with a transient temperature up to 160°F (exceeding the standard maximum temperature of 140°F). In evaluating such a case the pipe wall thickness shall be based on a design temperature of 140°F.

The rate process method (RPM) equation is used to evaluate PE 4710 piping for this 160°F temperature that is designed for a temperature of 140°F so that an excessively thick pipe will not be required.

In order to address a temperature of 160°F, the 160°F HDB of 800psi must be derived (100,000-hour value for an LTHS between 760psi and 960psi per Table 1 of ASTM D2837). This 160°F, 800psi HDB is then validated per ASTM D2837, Table 7.

The RPM equation with coefficients derived from typical PE 4710 linear regression curves for 73°F, 140°F and 176°F is used to derive the 160°F PE 4710 linear regression curve (See Appendix C) . This curve is then extrapolated to the 100,000-hour, the 438,000-hour (50-years), and the 525,600-hour (60-year) intercepts (the 100,000-hour intercept confirms an 800psi HDB).

The RPM method can be used as a way to create a math model of the PE 4710 creep rupture regression curves, but not for the testing used to establish these curves. There are 4 different ASTM D2837 methods (Procedures I, II, III or IV, which include the RPM and ISO 9080 methods) that can be used for the testing to establish HDB's for various temperatures (73°F, 140°F, 176°F, etc.)

The Rate Process Method uses the following equation. As explained in Appendix C of EPRI report 1013549, for a given HDPE material one needs stress rupture regression curve data for at least two temperatures and two stresses at two different failure times to determine the A, B, and C coefficients used in the RPM equation for the HDPE material involved.

$$Log(t) = A + \frac{B}{T} + \frac{C \times LogS}{T}$$

Where:

t = slit mode failure time, hours
T = absolute temperature, R
S = HDB hoop stress, psig

Once the three-coefficients are solved for, the equation can be used for the specific material involved to solve for any one parameter if the other two are given (i.e., given time and temperature, solve for stress).

As described in PPI TN-16/2008, a number of state-of-the-art PE resins (bimodal PE4710), when properly extruded into pipe, will not exhibit slit mode failures in reasonable test times even when tested at the maximum temperature (ductile type failure may occur). Therefore, the RPM procedure is not applicable for testing these materials except as a qualifying procedure to ensure, in fact, slit mode failures do not occur.

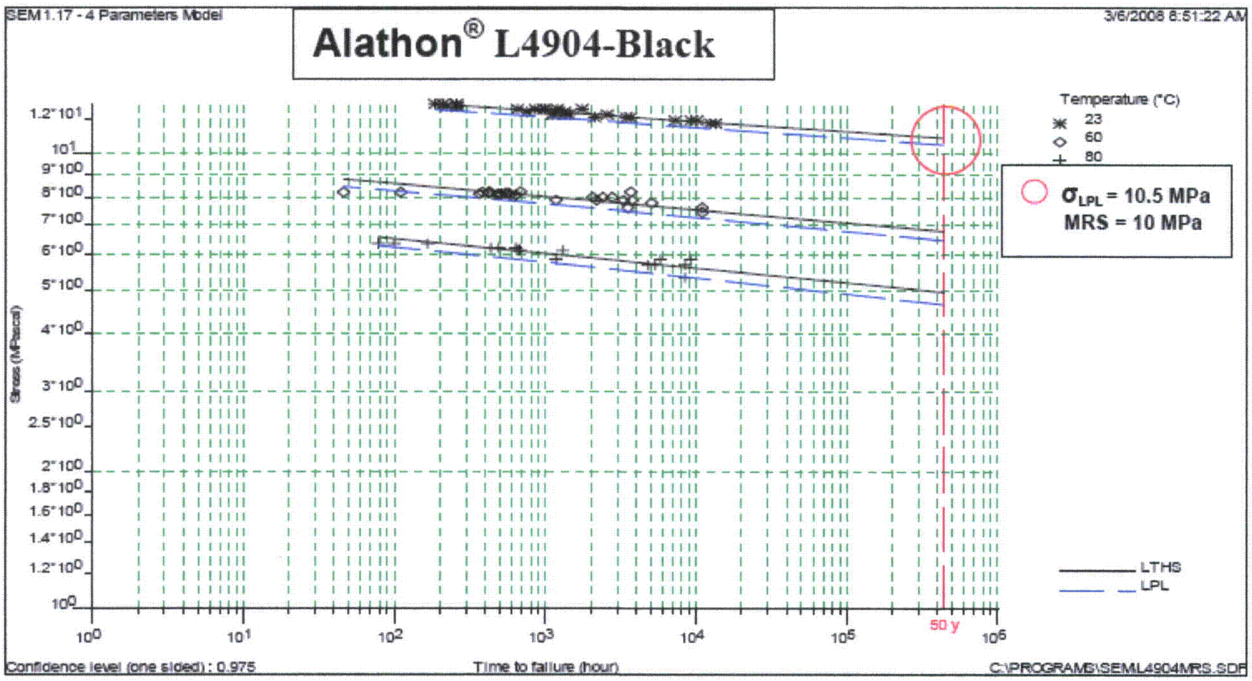
Where regression curves have been established by using one of the other ASTM methods, the RPM method can be used as a way to create a math model of these curves, even though it may not be suitable for testing purposes.

The regression curves are linear on a logarithmic grid, with the curves for each temperature parallel to one another. These curves can be used with the RPM method to predict material performance for stress and temperature values that lie between the curves, including the RPM extrapolation of these curves to a design life beyond 60 years.

Typical curves appear as follows:

**ISO 9080 Regression Analysis**

per Becetel's Standard Extrapolation Method (SEM) Software




EPRI Report 1013549, updated September 2006, Appendix C, uses the RPM method to predict the 60 year HDB for PE 3408 pipe (PE 3408 is not a bimodal high performance PE material).

Per ASTM D2837 Table 7, the linear regression curve for 176°F is extrapolated to the 37,500-hour intercept to confirm that this HDB exceeds the ASTM D2837 Table 7 value required to validate an 800psi HDB. A Design Factor (DF) of 0.50 was used to derive the 160°F HDS of 400psi.

To verify whether pipe with a wall thickness based on the 140°F HDS of 500psi (allowable pipe stress) can be used for the transient design temperature of 160°F, the RPM equation is used to calculate the pipe's time to rupture at 160°F with a pipe stress of 500psi, given that this pipe stress is 100psi higher than the 160°F HDS of 400psi (the design pressure is the same for both temperatures).

With this thinner pipe wall, the calculated time to rupture is 61 days. This 61-day duration exceeds the one-month duration (one half of the 160°F design life) for an event that occurs once in the 60-year plant life during which this 160°F design condition exists.

As noted in Section 9.2, with a pipe wall selected for the 140°F design condition, the pipe stress under normal operating conditions will be approximately 25% less than the HDS for the normal operating temperature, and the pipe's design life under normal operating conditions will exceed 1000 years. One half of the pipe's remaining design life is 1/2 x 1000 years = 500 plus years, which exceeds the required 60 year plant life.

9.5 Fatigue Loading

9.5.1 The mechanical properties used in design shall be consistent with the load duration. The elastic modulus varies significantly with the load duration, therefore, care must be taken in selecting the appropriate modulus for a given loading. Durations are given as follows:

Long Term Internal Pressure – 60 years

Thermal Loads – 1000 hours

Surge Pressures (water hammer) – Short term

Dead Load on buried piping – 60 years

Live Loads on buried piping (vehicles, railroads, etc.) – 10 hours

Soil Settlement Loads – 60 years

Overburden Loads – 60 years

Effects of Flood Loads – 100 hours

Seismic Loads – Short Term

The allowable stress or strain for these load conditions may either use the longer duration allowable stress or strain (conservative) or the allowable stress or strain may be consistent with the load duration. When checking the various criteria that include loads of different duration with consistent properties, the fatigue evaluation of design life shall be used.

Class 3 piping will be evaluated for fatigue due to thermal cycles, indicating that a fatigue factor, *f*, as determined in Table ND-3611.2(e)-1 of ASME Section III, "Stress Range Reduction Factor" will be used. This table requires use of a "Stress Range Reduction Factor" only when the number of full temperature cycles over the 60 year plant design life exceeds 7000 cycles.

The ASME Section III, Class 3 buried HDPE piping systems have redundancy, where half of the systems operate continuously under normal operating conditions (even during refueling), while the other half are in standby mode. As noted above, maximum operating (design) conditions rarely occur, are of a very short duration, and can be due to a DBA, the system's pump shutoff head, extreme ambient conditions, or combination of these events.

As noted in EPRI Report 1013572, An Integrated Project Plan to Obtain Code and Regulatory Approval to Use High-Density Polyethylene in ASME Section III, Class 3 piping applications, normal operation in these buried HDPE piping systems is essentially a steady state condition with little or no temperature variation (e.g. thermal cycling associated with changes to water or ground temperature), where temperature changes are small and gradual. It is estimated that full temperature cycles over the 60 year plant service life will be less than 7000 cycles (testing, switching between operating and standby equipment, full range temp cycles), therefore, the fatigue due to thermal cycles will be negligible.

### 9.5.2 Pressure Surge Events

Pressure surge events give rise to a rapid and temporary increase in pressure in excess of the steady state condition. For many pipe materials repeated and frequent pressure oscillations can cause gradual and cumulative fatigue damage which necessitate specifying higher pressure class pipes than determined solely based on sustained pressure requirements.

Two properties distinguish PE pipes from other types of pipes. The first is a lower stiffness which results in a significantly lower peak surge pressure generated by a sudden change in velocity when compared to metallic pipes with a higher stiffness.

The second is that a higher pressure rating (PR), or pressure class (PC), is generally not required to cope with the effects of pressure surges. Research, backed by extensive actual experience, indicates that HDPE pipes can safely tolerate the commonly observed maximum peak temporary surge pressure of twice the steady state condition. Furthermore, the long-term strength of PE pipes is not adversely affected by repeated cyclic loading; that is, HDPE pipes are considered fatigue resistant.

An evaluation of PE pipe stress/strain behavior gives further support to its capacity for safely tolerating occasional pressure surges. When a PE pipe is subjected to an add-on stress of very short duration, the resultant additional strain is relatively small, as predicted by the higher apparent modulus that covers this situation. Essentially all of this strain is elastic, meaning that as soon as the surge pressure has subsided, the added strain is reversed. Because this temporary strain is fully recovered, the minimal pipe expansion that occurs during a short lived surge pressure event has no effect on the longer term creep expansion that occurs under the sustained stress that is induced by a steady operating pressure. Surge pressure events of very short term duration have no adverse effect on PE's long term hydrostatic strength (LTHS).

# 10.0 QA/QC REQUIREMENTS

## 10.1 Qualifications of Suppliers

The Polyethylene material shall be procured from a qualified Certificate Holder with a Quality Assurance Program that meets 10CFR50 Appendix B requirements as follows:

### 10.1.1 Common Requirements

A. The Certificate Holder responsible for the installation of the polyethylene pipe shall assure that the material meets the requirements in the Design Specification.

B. The Certificate Holder shall perform any of the functions required by their respective Quality Assurance Program that are not performed by the Polyethylene Material Organization. The Certificate Holder may also elect to perform any other Quality Program functions, which would normally be the responsibility of the Polyethylene Material Organization. The functions shall be clearly defined in the Certificate Holders Quality Assurance Program.

C. The Certificate Holder shall make all necessary provisions so that the assigned Authorized Inspection Agency can make inspections necessary to comply with this Topical Report.

D. In accordance with NCA-8120(b), a Certificate of Authorization may be issued by ASME to an organization certifying joining by fusing.

### 10.1.2 New Construction

The Certificate Holder shall follow the requirements of NCA-3970 and NCA-4110 given in Appendix D of this Topical Report. These requirements have also been added to the 2010 Edition of the ASME Boiler and Pressure Vessel Code.

### 10.1.3 Section XI Repair/Replacement Activity

A. The Owner shall be responsible for qualification and auditing of the Polyethylene Material Organization.

B. The audit of the Polyethylene Material Organization shall establish that the Quality System Program conforms to the Owner's Quality Program.

C. Satisfactory completion of the audit will allow the Polyethylene Material Organization to supply material to the Owner for a period of three years, as long as there has not been a decline in performance, a significant change to the program, a change in scope of supply, a change in product line or design, or other changes based on reviews. After one year, and for each year thereafter, an audit shall be performed to assure continued program maintenance.

10.2 PE Procurement Supply Chain

10.2.1 When the Quality System surveys/audits required by Section 10.1 have been completed, the Certificate Holder shall establish a qualified PE supply chain.

A. The PE Source Material Manufacturer is the organization which manufactures and certifies the base PE material pellets.

B. The PE Material Manufacturer is the organization which manufactures and certifies PE components. The PE Material Manufacturer shall perform or shall supervise and directly control one or more of the operations which affect the PE material properties capable of meeting the requirements of the basic material specification. The satisfactory completion of all other requirements performed by other organizations prior to the certification shall be verified by the Material Manufacturer.

C. The PE Material Supplier is an organization which supplies products of the PE Material Manufacturer, but does not perform any operations which affect the PE materials properties required by the basic material specification.

10.2.2 Pressure retaining PE material used in construction of components shall be supplied with a Certified PE Test Report. These documents shall include the results of analysis and production tests performed on the PE material.

10.2.3 When the approved PE Material Manufacturer program relies on audits and certification, the Certified PE Test Report shall include PE material identification, physical property test results, and melt index temperature (when required by a Certificate Holder).

10.2.4 Certified PE Test Report shall include PE material identification (cell classification), physical property test results (includes in-situ and final tests), melt index temperature, mechanical property test results, and shall certify that the product was made from virgin pellets (no scrap or regrind material). Test data shall be supplied that provides the basis for the allowable stress values used for the supplied HDPE material. The product form shall be permanently marked.

10.3 Materials

10.3.1 General

A. PE material and components shall be procured using the requirements of this Topical Report and the following additional requirements:

1) PE material shall be selected from approved ASTM standards listed in Appendix B, and shall have material properties not less than those for cell classification 445574C per ASTM D 3350-05 (PE 4710). The actual material will be specified and purchased by the D3350-05 cell classification and Appendix B requirements (minimum PENT 2000 hrs, etc).

2) Only PE pipe, mitered elbows, and flanges using carbon black pigment shall be used.

3) PE product forms (pipe, mitered elbows, and flanges) shall conform to the ASTM Standards identified in Appendix B, as applicable.

B. PE material shall be marked in accordance with the marking requirements of Section 10.5.2.

C. Metallic materials and components shall be procured using the requirements of ASME Section III, Division 1 Subsection ND.

10.3.2 Mitered Elbows

The mitered elbow fabricator shall ensure the following requirements are met:

A. The configuration of the mitered elbow shall meet the requirements of Section 3.10.8.

B. Fabrication processes used in the fabrication of the mitered elbow shall meet the requirements of Sections 7.0, 8.6 and 8.7.

C. Mitered elbows shall have the fused joints inspected and accepted in accordance with Section 8.0.

D. Data Report Form TR-1 shall be used for this product form (see Appendix A).

10.3.3 Flange Adapter

The flange adapter fabricator shall ensure the following requirements are met:

A. The pressure rating of the polyethylene flange adapter is equal to or greater than the attached straight pipe.

B. The material cell classification shall not be less than 445574C per ASTM D 3350-05 (PE 4710).

C. The material is a bimodal resin and satisfies all the requirements of Appendix B.

D. The steel backing ring for the polyethylene flange adapter shall comply with requirements of ASME Section III paragraph ND-3647 except that the inside diameter of the backing ring will be manufactured to match the polyethylene flange stub outside diameter.

10.3.4 PE Material Fusing Qualification Testing

A. General

1) Each PE material used in accordance with this Topical Report shall be tested for compliance with Section 8.7 Fusion Procedure Specification (FPS)

2) Each PE Material tested shall be from the same PE Material Manufacturer's facility that supplies the PE material used in accordance with this Topical Report.

3) Joint Testing shall include the following configurations

   *a.* Using the same or different PE source materials from the same PE Material Manufacturer, in all combinations.

   *b.* Using the same or different PE source materials supplied by different PE Material Manufacturers, in all combinations.

B. Fusing Essential Variable For Testing

One joint shall be made of each of the following conditions:

1) Interfacial pressure of 90 psi and heater temperature of 450 °F
2) Interfacial pressure of 60 psi and heater temperature of 450 °F
3) Interfacial pressure of 90 psi and heater temperature of 400 °F
4) Interfacial pressure of 60 psi and heater temperature of 400 °F

C. Testing

Testing of the joints shall be in accordance with 8.6.2.A.

10.3.5 Qualifications of Materials

Upon Satisfactory review of the documentation supplied in accordance with Appendices B and D requirements, and confirmation that requirements listed in 10.3.1 through 10.3.4 above have been met, the PE fittings and pipe material shall be considered qualified for installation. PE Material Supplier shall supply documentation that the product form was adequately stored to prevent damage.

10.4 Examination and Repair of Material

10.4.1 Examination

A. PE material external surfaces shall be given a visual examination prior to installation. During a visual inspection the maximum allowed surface flaw is an indentation of 10% of the pipe wall thickness, or a notch depth of 0.125", which ever is smaller.

B. Personnel performing the examination shall be qualified in accordance with Section 8.2.

10.4.2 Repair of Material

The Non Conformance Reporting (NCR) process will be used to document as found conditions and repair of HDPE material.

Surface gouges or cuts that are less than the defect described in Section 10.4.1 and do not interfere with the minimum required wall thickness, may be removed by grinding or machining in accordance with the following requirements:

The repaired pipe may be used as-is provided:

A. The removed area has a minimum taper of 3:1 without sharp edges (width: height), and,

B. The remaining wall thickness is in excess of $t_{design}$ required by this Topical Report.

C. If the damaged area is in the flange face, the entire flange can be removed or the face can be refaced. The flange adapter fabricator shall ensure the pressure rating of the refaced flange adapter, based on a design factor (DF) of 0.5, is greater than or equal to the Design Pressure ($P_D$) of the attached straight pipe.

D. If the damaged area is in the flange hub, and gouges or cuts are less than the defect described in Section 10.4.1, the hub can be repaired as described in "A" above.

10.5 PE Material Organization's Quality Systems

10.5.1 Quality System Program

See Appendix "D" Paragraph NCA-3970.

10.5.2 Quality Program Requirements

See Appendix "D" Paragraph NCA-3973.

10.5.3 Responsibility of Constructor or Fabricator

A. The Constructor or Fabricator responsible for the placement of PE materials shall assure that the PE meets the requirements of the Construction Specification, and that tests performed by the PE Material Manufacturer and the PE Source Material Manufacturer meet the requirements of ASME Section III, Division 1 and this Topical Report.

B. The Constructor or Fabricator shall survey, audit, and qualify the Quality Assurance Program of the PE Material Manufacturer if a Quality System Certificate is not obtained.

C. The Constructor or Fabricator shall perform any of the functions required by NCA-4000 which are not performed by the PE Material Manufacturer. The Constructor or Fabricator may elect to perform other Quality Program functions which would normally be the responsibility of the PE Material Manufacturer.

D. The Constructor or Fabricator shall make all necessary provisions so that the Authorized Inspector and his Authorized Inspection Agency can make the inspections necessary to comply with the ASME Code and this Topical Report.

E. The functions performed by the Constructor or Fabricator shall be clearly defined and included in its Quality Assurance Program.

10.5.4 Responsibility of the PE Source Material Manufacturer

See Appendix "D" Paragraph NCA-3971.1.

10.5.5 Responsibility of the Natural Compound Manufacturer

See Appendix "D" Paragraph NCA-3971.2.

10.5.6 Responsibility of the Pigment Concentrate Compound Manufacturer

See Appendix "D" Paragraph NCA-3971.3.

10.5.7 Responsibility of the PE Compound Manufacturer

See Appendix "D" Paragraph NCA-3971.4.

10.5.8 Responsibility of PE Material Manufacturer

See Appendix "D" Paragraph NCA-3971.5.

10.5.9 Responsibility of PE Material Supplier

See Appendix "D" Paragraph NCA-3971.6.

10.5.10 Responsibility of PE Service Supplier

See Appendix "D" Paragraph NCA-3971.7.

10.6 Evaluation of Quality System

10.6.1 Evaluation by ASME Certificate Holders

See Appendix "D" Paragraph NCA-3972.1.

10.6.2 Evaluation of PE Service Suppliers by the PE Source Material Manufacturer or PE Material Manufacturer

See Appendix "D" Paragraph NCA-3972.2.

10.6.3 Evaluation of PE Service Suppliers of Calibration Services by the PE Service Suppliers

See Appendix "D" Paragraph NCA-3972.3.

10.7 Certification Requirements

10.7.1 Certificates of Analysis

See Appendix "D" Paragraph NCA-3974.1.

10.7.2 Certified PE Test Reports

See Appendix "D" Paragraph NCA-3974.2.

10.7.3 Additional Certification Requirements

See Appendix "D" Paragraph NCA-3974.3.

10.7.4 Quality System Program Statement

See Appendix "D" Paragraph NCA-3974.4.

# 11.0 COL REQUIREMENTS

Licensee submittals of U.S. EPR™ COL applications in accordance with RG 1.206 do not currently reflect the use of HDPE for any plant piping system. Upon approval of this Topical Report, a License Amendment Request will be submitted to revise FSAR Chapter 1.9, and 3.12 ASME Code Class 1, 2, and 3 Piping Systems, Piping Components, and Their Associated Supports; the specific systems in which the HDPE piping is to be used; and COL Section 10 ITAAC and ITAAC Closure. This Topical Report will be referenced in the applicable sections or specific information incorporated into the COL application subsections as appropriate.

There are several ITAAC identified in the COL application that will be impacted by the use of HDPE piping. In addition, the COL items, the table for Buried Duct Banks and Pipes, and the tables for the specific systems in which the HDPE will be used will be reviewed and revised where necessary to reflect the appropriate inspections, tests, and analyses discussed in Section 8.11 of this Topical Report.

Since this Topical Report references piping analysis programs for HDPE piping in addition to those programs referenced in Topical Report ANP-10264 for metal pipe, the applicable COL item will also be supplemented to reference this TR. The use of HDPE piping does not impact the U.S. EPR™ Design Control Document.

## 12.0 SUMMARY AND CONCLUSIONS

High Density Polyethylene, specifically PE 4710, is a very robust material, which resists erosion, corrosion, and prevents the growth of microbiological organisms. Microbiological Influenced Corrosion of buried water systems has plagued many of the current nuclear power plant fleet. High Density Polyethylene piping is a suitable alternative for the buried carbon steel piping.

This Topical Report provides the requirements for the design, analysis, fabrication, and installation of High Density Polyethylene piping in ASME Section III, Class 3 applications in order to adhere to the requirements of Title 10 of the Code of Federal Regulations and the Boiler and Pressure Vessel Code provided by the American Society of Mechanical Engineers. This is accomplished by utilizing industry codes and standards from ASME, ASTM, PPI, EPRI, Regulatory Guides, and industry experience with HDPE piping. This Topical Report is similar to other nuclear industry relief requests and code cases modified as a result of industry experience and increased knowledge on the subject of High Density Polyethylene piping.

This Topical Report demonstrates that HDPE 4710 piping is suitable for buried pipe applications for a Design Pressure up to 200psig, a Design Temperature up to 140°F, and a 60-year service life. Approval for HDPE piping identified herein is requested for a period of 40 years, consistent with the license term of a Combined License.

Adhering to the guidance provided by this Topical Report for the design, analysis, installation, and acceptance criteria, will result in the buried HDPE system being designed to industry requirements providing acceptable levels of safety to the public.

## 13.0 REFERENCES

13.1 Plastic Pipe Institute (PPI)

13.1.1 PPI TR-3-2010, Policies and Procedures for Developing Hydrostatic Design Basis (HDB), Pressure Design Basis (PDB), Strength Design Basis (SDB) and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe

13.1.2 PPI TR-4-2010, PPI Listing of Hydrostatic Design Basis (HDB), Hydrostatic Design Stress (HDS), Strength Design Basis (SDB), Pressure Design Basis (PDB) and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe

13.1.3 PPI TR-33-2006, Generic Butt Fusion Joining Procedure for Field Joining of PE Pipe

13.1.4 PPI TN-16-2008, Rate Process Method for Projecting Performance of PE Piping Components

13.1.5 PPI TN-38-2007, Bolt Torque for PE Flanged Joints

13.1.6 PPI TN-42-2009 “Recommended Minimum Training Guidelines for PE Pipe Butt Fusion Joining Operators for Municipal and Industrial Projects”

13.1.7 PPI Handbook on Polyethylene Piping, Second Edition

13.2 International Standards Organization (ISO)

13.2.1 ISO TR 19480-2005 "Thermoplastics Pipes and Fittings for the Supply of Gaseous Fuels or Water – Guidance for Training and Assessment of Fusion Operators."

13.3 American Society of Mechanical Engineers (ASME)

13.3.1 Boiler and Pressure Vessel Code 2001 Edition through 2003 Addenda

A. Section III, Division 1, Subsection ND

B. Section III, Division 1, Subsection NCA

C. Section V, Nondestructive Examination

D. Section XI, Rules for In-service Inspection of Nuclear Power Plants

E. B16.5-07, Pipe Flanges and Flanged Fittings: NPS 1/2 through 24

F. B16.47-06, Large Diameter Steel Flanges: NPS 26 Through NPS 60 Standard

G. B31.3-06, Process Piping

13.3.2 ASME Boiler and Pressure Vessel Code, Section III, Division 1, Code Case N755, “Use of Polyethylene (PE) Plastic Pipe Sections III, Division I and XI,” Revision 0, March 22, 2007

13.4 American Society for Testing and Materials (ASTM)

13.4.1 D422-63(re-approved 07), Standard Test Method for Particle – Size Analysis of Soils

13.4.2 D638-08, Standard Test Method for Tensile Properties of Plastics

13.4.3 D698-07, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft$^3$)

13.4.4 D746-07, Standard Test Method for Brittleness Temperature of Plastics and Elastomers by Impact

13.4.5 D792-08, Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

13.4.6 D1140-00, Standard Test Method for Amount of Materials in Soils Finer than No. 200 Sieve

13.4.7 D1238-04c, Standard Test Method for Melt Flow Rates of Thermoplastics by Extrusion Plastometer

13.4.8 D1505-03, Standard Test Method for Density of Plastics by the Density-Gradient Technique

13.4.9 D1556-07, Standard Test Method for Density of Soil in Place by the Sand-Cone Method

13.4.10 D1557-09, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft$^3$)

13.4.11 D1598-02(re-approved 09), Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure

13.4.12 D1603-06, Standard Test Method for Carbon Black Content in Olefin Plastics

13.4.13 D2216-05, Standard Method of Laboratory Determination of Moisture Content of Soil

13.4.14 D2290-08, Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe by Split Disk Method

13.4.15 D2412-02(re-approved 08), Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading

13.4.16 D2487-06, Classification of Soils for Engineering Purposes

13.4.17 D2774-08, Standard Practice for Underground Installation of Thermoplastic Pressure Piping

13.4.18 D2837-08, Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products

13.4.19 D3035-08, Standard Specification for PE Plastic Pipe (DR-PR) Based on Controlled Outside Diameter

13.4.20 D3261-10a, Standard Specification for Butt Heat Fusion Polyethylene (PE) Plastic Fittings for PE Plastic Pipe and Tubing

(D3261-10a is for molded fittings, and shall be used only for molded flange adapters)

13.4.21 D3350-10, Standard Specification for PE Plastics Pipe and Fittings PE Compounds

13.4.22 D4218-96(re-approved 08), Standard Test Method for Determination of Carbon Black Content in PE Compounds by the Muffle-Furnace Technique

13.4.23 D4253-00(re-approved 06), Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table

13.4.24 D4318-05, Test Methods for Liquid Limit, Plastic Limit & Plasticity Index of Soils

13.4.25 D4883-08, Standard Test Method for Density of Polyethylene by the Ultrasound Technique

13.4.26 F412-09, Standard Terminology Relating to Plastic Piping Systems

13.4.27 F714-08, Standard Specification for PE Plastic Pipe (SDR-PR) Based on Outside Diameter

13.4.28 F1668-08, Standard Guide for Construction Procedures for Buried Plastic Pipe

13.4.29 F1473-07, Standard Test Method for Notch Tensile Test to Measure the Resistance to Slow Crack Growth of PE Pipes and Resins

13.4.30 F2164-02(re-approved 07), Standard Practice for Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Hydrostatic Pressure

13.4.31 F2206-02, Standard Specification for Fabricated Fittings of Butt-Fused PE Plastic Pipe, Fittings, Sheet Stock, Plate Stock, or Block Stock

13.4.32 F2263-09 Standard Test Method for Evaluating the Oxidative Resistance of PE Pipe to Chlorinated Water

13.4.33 F2620-09 $^{\varepsilon1}$ Standard Practice for Heat Fusion Joining of PE Pipe and Fittings, (Superscript $^{\varepsilon1}$ is for minor March 2010 editorial Change)

13.4.34 F2634-07 Standard Test Method for Laboratory Testing of Polyethylene (PE) Butt Fusion Joints using Tensile-Impact Method

13.4.35 F2769-09, Standard Specification for PE of Raised Temperature (PE-RT) Plastic Hot and Cold-Water Tubing and Distribution Systems

13.5 Nuclear Regulatory Commission (NRC)

13.5.1 Regulatory Guide 1.29-2006, Seismic Design Classification, Revision 3

13.5.2 Regulatory Guide 1.206-2007, Combined License Applications for Nuclear Power Plants

13.5.3 NUREG 0800, SRP 3.9.3-2007, ASME Code Class 1, 2, and 3 Components, and Component Supports, and Core Support Structures

13.5.4 NUREG 0800, SRP 3.7.3-2007, Seismic Subsystem Analysis

13.5.5 NUREG-1367, Functional Capability of Piping System, Nov 1992

13.5.6 NUREG-0484, Methodology for Combining Dynamic Responses, Revision 1

13.5.7 ML063120215, Catawba, Units 1 & 2 Request for Relief Number 06-CN-003 Use of Polyethylene Material in Nuclear Safety Related Piping Applications, 2006

13.5.8 ML082470210, Callaway, Unit 1, 10CFR50.55a Request: Proposed Alternative to ASME Section XI Requirements for Replacement of Class 3 Buried Piping, 2008.

13.6 Code of Federal Regulation

13.6.1 10 CFR Part 100, Reactor Site Criteria

13.6.2 10 CFR 50.55a, Codes and Standards

13.6.3 10 CFR Part 50, Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants

13.6.4 10 CFR Part 52, Licenses, Certifications, and Approvals for Nuclear Power Plants

13.7 EPRI Documents

13.7.1 Nondestructive Evaluation: Seismic Design Criteria for Polyethylene Pipe Replacement Code Case, 1013549, 2006

13.7.2 An Integrated Project Plan to Obtain Code and Regulatory Approval to Use High-Density Polyethylene in ASME Class 3 Piping Applications, 1013572, 2006

13.7.3 Fatigue Testing of High Density Polyethylene Pipe and Components Fabricated from PE 4710 – 2008 Update, 1016719, 2008

13.7.4 Fatigue and Capacity Testing of High-Density Polyethylene Pipe and Pipe Components Fabricated from PE4710, 1015062, 2007

13.8 American Society of Civil Engineers (ASCE)

13.8.1 Guidelines for the Seismic Design of Oil and Gas Pipeline Systems, 1984, ASCE

13.8.2 ASCE 4, Seismic Analysis of Safety-Related Nuclear Structures and Commentary

13.9 Other Documents

13.9.1 Guideline for the Design of Buried Steel Pipe; Report by American Lifelines Alliance, 2001, with February 2005 addendum.

13.9.2 ISO 9080 Regression Analysis of the Pipe Grade HDPE CONTINUUM DGDA 2490 BK, Dow

13.9.3 ISO 9080 Regression Analysis per Becetel's Standard Extrapolation Method (SEM) Software, Lyondell Basell

13.9.4 ISO 12176-1 Plastics Pipes and Fittings – Equipment for Fusion Jointing Polyethylene Systems – Part 1: Butt Fusion.

13.9.5 PE Pipe – Design and Installation, Manual M55, American Water Works Association, 2006

13.9.6 Jana Technical Report "Long-Term Performance of PE Piping Materials in Potable Water Applications" (9/17/2009)

13.9.7 ANP-10264NP-A, Revision 0, U.S. EPR™ Piping Analysis and Pipe Support Design

13.9.8 "Intrinsic Lifetime of Polyethylene Pipelines", Journal of Polymer Engineering and Science, Norman Brown, Issue 4, April 2007

## APPENDIX A: Forms

## Form TR-1: DATA REPORT FOR NON-METALLIC BATCH PRODUCED PRODUCTS REQUIRING FUSING

As Required By the Provisions of ASME Section III, Division I, and Topical Report URS-TR300370NP

1. Manufactured by: ____________________
(name and address of manufacturer of Non metallic products)
2. Manufactured for: ____________________
(name and address of purchaser)

3.a Identification-Certificate Holders Serial No. ____________________
(Lot No. Batch No., Etc.) (print string)
____________ (National Bd. No.) ____________ (year of manufacturing)

3.b Owner ____________________

4. Manufactured according to Material Spec ________ (ASTM) Purchase Order No. ________

5. Remarks ____________________
(brief description of fabrication)
____________________
____________________
____________________

### CERTIFICATE OF COMPLIANCE

We certify that the statements made in this report are correct and that the products defined in this report conform to the requirements of the ASME material specification listed above on line 4, the Certified Material Batch Reports provided for the material covered by this report.
Certificate of Authorization (NA if owner) No. ________ to use the ________ Symbol expires ________ (Date)

Date ________ Name ____________ (Certificate Holder) Signed ____________ (authorized representative)

### Certificate of Inspection

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State of ____________ and employed by ____________ of ____________ have inspected the products described in this Partial Data Report product in accordance with ASME Section III, Division 1, and Topical Report (URS-TR-300370NP). By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the products described in this Partial Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ________ Signed ____________ (Authorized Nuclear Inspector) Commissions ____________ (National Board, state, and No.)

# Form TR-2: FUSION PROCEDURE SPECIFICATION

Prepared by: ____________________ Date ________
Approved by: ____________________ Date ________

| | |
|---|---|
| Material ____________________ | Fusion Drag Pressure ____________________ |
| | Fusion Pressure ____________________ |
| | Bead-up Size ____________________ |
| | Heater Removal Time ____________________ |
| Fusion Material Info ____________________ | Cool Time and Fusion Pressure ____________________ |
| Data Acquisition MFR ____________________ | |
| Data Acquisition Attached ____________________ | |
| Fusion Interfacial Pressure ____________________ | |
| Heater Surface Temperature ____________________ | |

Technique ____________________

# Form TR-3: FUSION MACHINE OPERATOR PERFORMANCE QUALIFICATION (FPQ) TEST FORM

Operators Name ______________________________

Payroll Number ______________________________

Stamp ID ______________________________

Lab Test Number ______________________________

Test: Qualification ______________ Re-qualification ______________

Fusion Machine Manufacturer ______________________________

Fusion Machine Pipe Size Range ______________________________

Test Position ______________________________

Material Specification ______________ to ______________

Fusion Specification Procedure ______________________________

Pipe Size ______________ Pipe DR ______________

NDE Requirements

Visual __________ Visual Results __________

Free Band Test __________ Free Band Test Results __________

Data Acquisition Record Review Results ______________________________

Test Conducted By ______________________________

We certify that the statements in this record are correct and that the fused joints are prepared in accordance with the requirements of Topical Report (URS-TR-300370NP)

Signed By ______________________________ Date ______________

# APPENDIX B: POLYETHYLENE COMPOUND AND POLYETHYLENE MATERIAL

## B.1 Polyethylene Compound and Polyethylene Material Requirements

### B.1.1 General Requirements

A. Natural Compound, Pigment Concentrate Compound, Polyethylene Compound and Polyethylene Material shall be procured using the requirements of this Appendix.

B. Conformance with the ASTM Standards referenced in Section 2.2 and herein shall be limited as specified in this Appendix. In the event of a conflict between a reference standard and this Appendix, the requirements of this Appendix shall prevail.

C. Natural Compound, Pigment Concentrate Compound, Polyethylene Compound, and Polyethylene Material shall be marked in accordance with the marking requirements in this Appendix, Appendix D and the applicable ASTM standard.

### B.1.2 Requirements for Polyethylene Compound, Natural Compound, and Pigment Concentrate Compound

A. Requirements for the Polyethylene Compound

1) General Requirements

   a. The Required Value for each Physical Property shall be specified in Table B-1.
   b. The Requirement Standard for determining the Required Value for Physical Properties shall be as specified in Table B-1.
   c. The Test Method for determination of the Required Value for Physical Properties shall be as specified in Table B-1.

2) Polyethylene Compound used for the manufacture of Polyethylene Material shall meet the requirements of the Polyethylene Compound Manufacturer, and the requirements of Table B-1.

3) Polyethylene Compound shall be black except as provided in Section B.1.3.A.2.

4) Polyethylene Compound is the combination of Natural Compound and Pigment Concentrate Compound as follows:

   a. When Polyethylene Compound is combined by the Polyethylene Compound Manufacturer, Polyethylene Compound is Polyethylene Source Material.
   b. When Polyethylene Compound is combined by the Polyethylene Material Manufacturer, Natural Compound and Pigment Concentrate Compound are the Polyethylene Source Materials.
   c. When Polyethylene Compound is combined by the Polyethylene Material Manufacturer, the Natural Compound Manufacturer shall provide the Polyethylene Material Manufacturer with a formulation that specifies the weight ratio (proportions) of Natural Compound and Pigment Concentrate Compound, and processing equipment setting recommendations that produce Polyethylene Compound in accordance with Table B-1.

5) The Polyethylene Compound shall have an independent listing that is published in PPI TR-4, Table I.A.13. The independent listing shall identify:

   a. A Standard Grade hydrostatic design basis, HDB, rating of at least 1,600 psi at 73°F;

b. A Standard Grade HDB rating of at least 1,000psi at 140°F;
c. A hydrostatic design stress, HDS, rating of at least 1,000psi for water at 73°F. The listed hydrostatic design stress, HDS, rating of at least 1,000psi for water at 73°F, shall be reduced to 800psi to reflect use of a DF of 0.5.
d. Standard Grade HDB ratings and HDS ratings shall be determined in accordance with PPI TR-3, Parts A, D and F.
e. The Polyethylene Compound shall have a Material Designation of PE4710 in accordance with PPI TR-4, Table I.A.13.
f. The unique trade name or designation for the Polyethylene Compound.
g. Polyethylene Natural Compound Manufacturer

6) The Polyethylene Material Manufacturer of polyethylene pipe shall have a dependent listing for black Polyethylene Compound that is published in PPI TR-4, Table I.A.13. The dependent listing shall identify:

a. A Standard Grade hydrostatic design basis, HDB, rating of at least 1,600psi at 73°F;
b. A Standard Grade HDB rating of at least 1,000psi at 140°F.
c. A hydrostatic design stress, HDS, rating of at least 1,000psi for water at 73°F. The listed hydrostatic design stress, HDS, rating of at least 1000psi for water at 73°F, shall be reduced to 800psi to reflect use of a DF of 0.5.
d. Standard Grade HDB and HDS ratings shall be determined in accordance with PPI TR-3 Parts A, D and F.
e. The Polyethylene Material Manufacturer shall assign a unique trade name or designation to the Polyethylene Compound that is published in PPI TR-4, Table I.A.13.

7) The Certificate of Analysis shall identify the trade name or designation assigned to the Polyethylene Compound by the Polyethylene Compound Manufacturer that is published in PPI TR-4.

8) The Certified Polyethylene Test Report shall identify the trade name for the Polyethylene Compound assigned by the Polyethylene Material Manufacturer that is published in PPI TR-4, Table I.A.13, and shall identify:

a. the Certificate of Analysis trade names for the Natural Compound and the Pigment Concentrate Compound, or
b. the Certificate of Analysis trade name for the Polyethylene Compound.

9) If specified, color Polyethylene Compound shall contain color and ultraviolet (UV) stabilization in accordance with ASTM D3350 Code E. Color Polyethylene Compound color and ultraviolet (UV) stabilization duration requirements shall be specified in the Design Specification. Per Section B.1.3.A.2, color Polyethylene Compound shall be used only for optional color stripes on Polyethylene Material in the form of pipe.

B. Natural Compound

1) Natural Compound shall meet requirements specified by the Natural Compound Manufacturer.

2) Natural Compound shall be combined with Pigment Concentrate Compound in accordance with Section B.1.2.A.4.

3) The Natural Compound Manufacturer shall assign a unique trade name or designation to the Natural Compound.

C. Pigment Concentrate Compound

1) Black Pigment Concentrate Compound shall meet requirements specified by the Natural Compound Manufacturer.

2) Black Pigment Concentrate Compound shall be combined with Natural Compound in accordance with Section B.1.2.A.4.

3) The Pigment Concentrate Compound Manufacturer shall assign a unique trade name or designation to the Pigment Concentrate Compound.

4) Color Pigment Concentrate Compound shall be in accordance with Section B.1.3.A.2 and Section B.1.3.A.2.b.

B.1.3 Polyethylene Material

A. Polyethylene Material– Pipe

1) PE Material in the form of pipe shall be manufactured in accordance with this Topical Report and ASTM D3035 for sizes below 3-inch nominal outside diameter or ASTM F714 for sizes 3- inch nominal outside diameter and larger. Elevated temperature sustained pressure test per ASTM D3035 of ASTM F714 shall be successfully completed twice annually.

2) Pipe shall be black and shall be manufactured by Plastic Extrusion. With the exception of optional color stripes, black pipe shall contain 2 to 3% carbon black that is well dispersed through the pipe wall when samples taken from pipe are tested per ASTM D1603 or ASTM D4218.

a. Optional color stripes that are coextruded into the pipe outside surface during plastic extrusion are acceptable. The depth of optional color stripes into the pipe outside surface shall not exceed 10% of the $t_{fab\ min}$ minimum wall thickness required for the pipe design stress. Color stripes shall not project above the pipe outside surface and shall not be covered in whole or in part by black pipe material.
b. Where Natural Compound and Pigment Concentrate Compound are combined by the Polyethylene Material Manufacturer, the Polyethylene Material Manufacturer shall use the same Natural Compound with black Pigment Concentrate Compound and with color Pigment Concentrate Compound if optional color stripes are coextruded into the pipe outside surface.
c. Where black Polyethylene Compound and color Polyethylene Compound are used to extrude pipe with optional color stripes, coextruded into the outside surface, the black Polyethylene Compound and color Polyethylene Compound shall have been combined using the same Natural Compound.

3) Pipe print line marking shall be applied during plastic extrusion using heated indentation.

4) Prior to shipment of the pipe, the purchaser may specify any testing requirements for the fusibility of the material per Section 10.3.4.

B. Polyethylene Material – Flange Adapter

This section provides requirements for flange adapters.

Prior to shipment of the pipe, the purchaser may specify any testing requirements for the fusibility of the material per Section 10.3.4.

1) Polyethylene Material - Machined Flange Adapter

The Polyethylene Material used to fabricate flange adapters that are machined from pipe shall meet the requirements of B.1.3.A.

2) Polyethylene Material – Molded Flange Adapter

This section provides the requirements for molded–to-size flange adapters and molded flange adapters that are machined to size.

The Polyethylene Compound used to manufacture molded flange adapters shall meet the requirements of B.1.2.A and shall be manufactured in accordance with this Topical Report.

B.2 Quality Assurance General Requirements

The Polyethylene Source Material Manufacturer and the Polyethylene Manufacturer shall have Quality Programs in compliance with NCA-3970 (2010 edition or later) or Appendix D of this Topical Report.

It is not the intent of this paragraph to require that individual lots of Polyethylene Source Material be qualified per B.1.2 because several of the B.1.2 qualification requirements are determined by tests of numerous samples for up to 10,000 hours (11.4 years) duration. However, the Polyethylene Source Material Manufacturer shall assure that B.1.2 Polyethylene Compound Qualification requirements are met through its Quality Program. In general, the minimum quality testing requirements in this Appendix are intended to provide traceability and to assure Polyethylene Material in accordance with the design requirements of this Topical Report.

B.2.1 Certificate of Analysis

The following contains requirements for Certificate of Analysis.

A. PE Compound Certificate of Analysis

1) Polyethylene Compound shall be qualified per Table B-1.

2) The Polyethylene Compound Manufacturer shall test Polyethylene Compound in accordance with Table B-2 and shall provide a Certificate of Analysis (C of A) to the purchaser of the lot.

3) The Certificate of Analysis shall provide the following information:

a. Certified test results in accordance with Table B-2;
b. The name of the Polyethylene Compound Manufacturer;
c. The manufacturing location;
d. A code or number that is unique and specific to the lot;
e. The Polyethylene Compound Manufacturer's trade name for the Polyethylene Compound as published in PPI TR-4;
f. The shipping method or type of container(s) for the lot such as railcar or boxes and additional information such as a railcar number if shipped by rail or the name of the commercial carrier and number of boxes if shipped by commercial carrier;
g. The lot quantity of Polyethylene Compound in pounds;
h. The date of shipment;

i. Other information that identifies the purchaser (customer), purchaser order, purchaser contact, purchaser delivery location, and contact information for the Polyethylene Compound Manufacturer.

B. Natural Compound Certificate of Analysis

1) The Natural Compound Manufacturer shall test Natural Compound in accordance with Table B-3. The Natural Compound Manufacturer shall provide a Certificate of Analysis to the purchaser of the lot.

2) The Certificate of Analysis shall provide the following information:

a. Certified test results in accordance with Table B-3;
b. The name of the Natural Compound Manufacturer;
c. The manufacturing location;
d. A code or number that is unique and specific to the lot;
e. The Natural Compound Manufacturer's trade name for the Natural Compound;
f. The shipping method or type of container(s) for the lot such as railcar or boxes and additional information such as a railcar number if shipped by rail or the name of the commercial carrier and number of boxes if shipped by commercial carrier;
g. The lot quantity of Natural Compound in pounds;
h. The date of shipment;
i. Other information that identifies the purchaser (customer), purchaser order, purchaser contact, delivery location, and contact information for the Natural Compound Manufacturer.

C. Pigment Concentrate Compound Certificate of Analysis

1) The Pigment Concentrate Compound Manufacturer shall test Pigment Concentrate Compound in accordance with Table B-4. The Pigment Concentrate Compound Manufacturer shall provide a Certificate of Analysis to the purchaser of the lot.

2) The Certificate of Analysis shall provide the following information:

a. Certified test results in accordance with Table B-4;
b. The name of the Pigment Concentrate Compound Manufacturer;
c. The manufacturing location;
d. A code or number that is unique and specific to the lot;
e. The name of the Pigment Concentrate Compound Manufacturer's trade name for the Pigment Concentrate Compound;
f. The shipping method or type of container(s) for the lot such as railcar or boxes and additional information such as a railcar number if shipped by rail or the name of the commercial carrier and number of boxes if shipped by commercial carrier;
g. The lot quantity of Pigment Concentrate Compound in pounds;
h. The date of shipment;
i. Other information that identifies the purchaser (customer), purchaser order, purchaser contact, delivery location, and contact information for the Pigment Concentrate Compound Manufacturer.

B.2.2 Certified Polyethylene Test Report for Polyethylene Material – Pipe

A. The Polyethylene Material Manufacturer of pipe shall verify Certificate of Analysis values by testing a sample from the Polyethylene Source Material lot in accordance with Table

B-5. The Polyethylene Source Material lot shall not be used when testing does not verify Certificate of Analysis values.

B. The PE Material Manufacturer of pipe shall test pipe in accordance with Table B-6 and shall provide a Certified Polyethylene Test Report (CPTR) to the purchaser.

C. For each lot, the CPTR shall provide the following information:

1) Certified test results for the lot in accordance with Table B-6;
2) The name of the Polyethylene Material Manufacturer;
3) The manufacturing location;
4) A code or number that is unique and specific to the lot;
5) The ASTM standard for pipe manufacture;
6) The specification for the Polyethylene Compound, e.g., this Topical Report, Mandatory Appendix B;
7) The shipping method and the name of the commercial carrier;
8) The lot quantity in feet;
9) The date of shipment;
10) Other information that identifies the purchaser (customer), purchaser order, purchaser contact, delivery location, and contact information for the Polyethylene Material Manufacturer.
11) A certification that the Polyethylene Material was made from only virgin polyethylene material and that no scrap or regrind material was used (see Appendix D NCA-3974.3).

B.2.3 Certified Polyethylene Test Report for Polyethylene Material – Molded Flange Adapters

A. The Polyethylene Material Manufacturer of molded flange adapters shall verify Certificate of Analysis values by testing a sample from the Polyethylene Source Material lot in accordance with Table B-5. The Polyethylene Source Material lot shall not be used when testing does not verify Certificate of Analysis values.

B. The PE Material Manufacturer of pipe shall test pipe in accordance with Table B-6 and shall provide a Certified Polyethylene Test Report (CPTR) to the purchaser.

C. For each lot, the CPTR shall provide the following information:

1) Certified test results for the lot in accordance with Table B-6;
2) The name of the Polyethylene Material Manufacturer;
3) The manufacturing location;
4) A code or number that is unique and specific to the lot;
5) The ASTM standard for molded fitting / flange adapter manufacture;
6) The specification for the Polyethylene Compound, e.g. this Topical Report Mandatory Appendix B;
7) The shipping method and the name of the commercial carrier;

8) The lot quantity in pieces;

9) The date of shipment;

10) Other information that identifies the purchaser (customer), purchaser order, purchaser contact, delivery location, and contact information for the Polyethylene Material Manufacturer.

11) A certification that the Polyethylene Material was made from only virgin polyethylene material and that no scrap or regrind material was used (see NCA-3974.3).

Table B-1: Compound Physical Properties

| No. | Property, units | Required Value | Requirement Standard | Test Method |
|---|---|---|---|---|
| 1 | Density, g/cm3 | a) 0.956 to 0.968 w/2-3% carbon black<br>b) 0.947 to 0.955 w/o carbon black or pigment | ASTM D3350 | ASTM D1505 or ASTM D792 or ASTM D4883 |
| 2 | High Load Melt Flow Rate, g/10 min | 4 to 20 | Polyethylene Compound Manufacturer Quality Program | ASTM D1238, Condition 190 / 21.6 |
| 3 | Carbon Black, % | 2 to 3 | ASTM D3350 and Table B-1 | ASTM D4218 or ASTM D1603 |
| 4 | Slow Crack Growth Resistance, hrs | > 2000 | ASTM D3350 and Table B-1 | ASTM F1473 |
| 5 | Thermal Stability, °F | > 428 | ASTM D3350 | ASTM D3350 |
| 6 | Tensile Strength at Yield, psi | ≥ 3500 | ASTM D3350 | ASTM D638, Type IV at 2in/min |
| 7 | Tensile Elongation at Break, % | ≥ 500 | ASTM D3350 | ASTM D638, Type IV at 2in/min |
| 8 | HDB at 73°F, psi | 1600 | ASTM D2837, PPI TR-3 and PPI TR-4 | ASTM D2837, PPI TR-3 and PPI TR-4 |
| 9 | HDB at 140°F, psi | 1000 | ASTM D2837, PPI TR-3 and PPI TR-4 | ASTM D2837, PPI TR-3 and PPI TR-4 |
| 10 | HDS for water at 73°F, psi | 1000 | ASTM D2837, PPI TR-3 and PPI TR-4 | ASTM D2837, PPI TR-3 and PPI TR-4 |
| 11 | Thermoplastic Pipe Material Designation Code | PE 4710 | Listed in PPI TR-4 | N/A |

Table B-2: Minimum Quality Test Requirements for Polyethylene Compound

| No. | Test | Test Standard | Test Frequency | Test Timing | C of A Reports Test Result |
|---|---|---|---|---|---|
| 1 | High Load Melt Flow Rate, Condition 190/21.6, g/10 min | ASTM D1238 and Table B-1 | Once per lot | N/A | Yes |
| 2 | Density | ASTM D792 or ASTM D1505 or ASTM D4883 and Table B-1 | Once per lot | Before lot shipment | Yes |
| 3 | Tensile strength at yield and tensile elongation | ASTM D638 and Table B-1 | Once per lot | Before lot shipment | Yes |
| 4 | Thermal Stability | ASTM D3350 and Table B-1 | Once per lot | Before lot shipment | Yes |
| 5 | Carbon black content | ASTM D1603 or ASTM D4218 and Table B-1 | Once per lot | Before lot shipment | Yes |

Table B-3: Minimum Quality Test Requirements for Natural Compound

| No. | Test | Test Standard | Test Frequency | Test Timing | C of A Reports Test Result |
|---|---|---|---|---|---|
| 1 | High Load Melt Flow Rate, Condition 190/21.6, g/10 min | ASTM D1238 | Once per lot | N/A | Yes |
| 2 | Density | ASTM D792 or ASTM D1505 or ASTM D4883 and Table B-1 | Once per lot | Before lot shipment | Yes |
| 3 | Tensile strength at yield and tensile elongation | ASTM D638 | Once per lot | Before lot shipment | Yes |
| 4 | Thermal Stability | ASTM D3350 | Once per lot | Before lot shipment | Yes |

Table B-4: Minimum Quality Test Requirements for Pigment Concentrate Compound

| No. | Test | Test Standard | Test Frequency | Test Timing | C of A Reports Test Result |
|---|---|---|---|---|---|
| 1 | Carbon black content (black only) | ASTM D1603 or ASTM D4218 | Every 24 hrs during lot production | Every 24 hrs after acceptable product has been produced for given production lot. | Yes |
| 2 | Color and UV stabilizer (color only) | ASTM D3350 | Every 24 hrs during lot production | Every 24 hrs after acceptable product has been produced for given production lot. | Yes |

Table B-5: Minimum Quality Testing Requirements for PE Source Material

| No. | Test | Test Standard | Test Frequency | C of A Reports Test Result |
|---|---|---|---|---|
| 1 | High Load Melt Flow Rate, Condition 190/21.6, g/10 min | ASTM D1238 (Ref: B.2.2.A) | Once per lot upon receipt at the processing facility | Yes |
| 2 | Density | ASTM D792 or ASTM D1505 (Ref: B.2.2.A), and Table B-1 | Once per lot upon receipt at the processing facility | Yes |
| 3 | Carbon black concentration percentage for black Polyethylene Compound or black Pigment Concentrate Compound | ASTM D1603 or ASTM D4218 (Ref: B.2.2.A) | Once per lot upon receipt at the processing facility | Yes |
| 4 | Slow Crack Growth Resistance(1), hrs | > 2000 hrs per ASTM F1473 completed on compression molded paque at 350psi and 176°F in Table B-1 | Once per lot prior to shipment of Polyethylene Material | Yes |
| 5 | Thermal Stability(1), °F | > 428°F ASTM D3350 and Table B-1 | Once per lot prior to shipment of Polyethylene Material | Yes |

(1)Note: In no case shall any individual test result used to establish this value in accordance with the reference industry standards be less than the minimum required value listed in this table.

Table B-6: Minimum Quality Testing Requirements for PE Material - Pipe

| No. | Test | Test Standard | Test Frequency | C of A Reports Test Result |
|---|---|---|---|---|
| 1 | Workmanship | ASTM D3035 for < 3" IPS<br>ASTM F714 for ≥ 3" IPS | Hourly or once per length, whichever is less frequent during ongoing production | Yes |
| 2 | Outside Diameter | ASTM D3035 for < 3" IPS<br>ASTM F714 for ≥ 3" IPS | Hourly or once per length, whichever is less frequent during ongoing production | Yes |
| 3 | Toe-In | ASTM D3035 for < 3" IPS<br>ASTM F714 for ≥ 3" IPS | Once per shift during ongoing production | Yes |
| 4 | Wall thickness | ASTM D3035 for < 3" IPS<br>ASTM F714 for ≥ 3" IPS | Hourly or once per length, whichever is less frequent during ongoing production | Yes |
| 5 | Short term strength | ASTM D3035 for < 3" IPS<br>ASTM F714 for ≥ 3" IPS | At the beginning of production and weekly thereafter during ongoing production | Yes |
| 6 | Carbon black content | B.1.3.A.2 | At the beginning of production and daily thereafter during ongoing production | Yes |

# APPENDIX C: Rate Process Method for HDB and Design Life

## C.1 Objective

The purpose of this appendix is to support the HDPE Topical Report for the U.S. EPR™ which plans to use HDPE pipe in a Safety Class 3 service water application. The plastic pipe industry currently qualifies PE4710, for 50 years up to 140°F, however the US EPR™ service water system is being designed for a temperature excursion up to 160°F for a period of 30 days, and a design life of 60 years. This appendix is intended to prove that the pipe can be designed for 140°F and still safely operate with a 30 day temperature excursion up to 160°F, for a 60 year plant design life. This appendix also establishes the 50 year and 60 year LTHSs for temperatures up to 160°F.

## C.2 Design Criteria

The following are the design parameters of the HDPE piping system:

Design Temperature: 140°F

Design Pressure: 200psig

Design Life: 60 years

HDS @ 140°F = 500psi (DF = 0.50)

Pipe wall DR = 2(HDS/P) +1 = 2(500/200) + 1 = 6

Normal Operating Parameters (see C.4.2)

Transient Parameters (see C.4.3)

## C.3 Methodology

The PPI Hydrostatic Stress Board (HSB) conducted an extensive evaluation of various methods for forecasting the effective long-term performance of polyethylene (PE) thermoplastic piping materials. Basically, these methods require elevated temperature sustained pressure testing of pipe where the type of failure is the slit or brittle-like mode.

As a result of this study, HSB determined that the three-coefficient Rate Process Method (RPM) equation provided the best correlation between calculated long-term performance projections and known field performance of several PE piping materials. It also had the best probability for extrapolation of data based on the statistical "lack of fit" test.

The Rate Process Method (RPM), which was developed out of this study, was incorporated into ASTM D2837. ASTM D2837 also includes a "validation" requirement for PE piping materials HDB. The RPM method can be used as a way to create a math model for the established regression curves, even though it may not be suitable for testing purposes. The regression curves are linear on a logarithmic grid, with the curves for each temperature parallel to one another. These curves can be used with the RPM to predict material performance for stress and temperature values that lie between the curves, including the RPM extrapolation of these curves beyond 60 years. EPRI Report 1013549, updated September 2006, Appendix D, uses the RPM to predict the 60 year LTHS for PE 3408 pipe (PE 3408 is not a bimodal high performance PE material).

Using the failure mode data points from the Lyondell Basell Alathon L4904-Black regression curves, the following equation can be solved for the coefficients A, B and C.

$$Logt = A + \frac{B}{T} + \frac{CLogS}{T}$$

Where:

t = slit mode failure time, hours

T = absolute temperature, R

S = LTHS, psi (based on a DF of 0.50), the LTHS= hoop stress x 2

This data is used to solve for the coefficients A, B, and C. The coefficients are used to solve the design life for the normal operating condition and elevated temperature excursion.

C.4 Calculations inputs

C.4.1 Data from the Regression Curve

The following data has been taken from the Lyondell Basell Alathon L4904-Black regression curves:

| Data From L4904 Regression Curve | | | | | |
|---|---|---|---|---|---|
| Temperature | | HDB (psi) | | Time to Failure (hrs) | |
| $T_1$= | 73°F | $S_1$= | 1581.05 | $t_1$ = | 100000 |
| $T_2$= | 140°F | $S_2$= | 971.835 | $t_2$ = | 100000 |
| $T_3$= | 176°F | $S_3$= | 797.775 | $t_3$ = | 21900 |

C.4.2 Normal Operating Parameters for the ESW Make-Up Water at 115°C

The following are the normal operating parameters for the ESW System

| | | |
|---|---|---|
| Temperature: | 115°F | (Normal Operating Temp) |
| Pressure: | 80psig | (Normal Operating Pressure) |
| Hoop Stress: | 200psi | (from hoop stress DR equation) |

$$S = \frac{P}{2}(DR-1) = \frac{80psig}{2}(6-1) = 200psi$$

Note d/t = IDR, 36/9=4 (DR=IDR+2=6)

For a Design Factor of 0.5, the LTHS used in the Rate Process Method is two times the operating hoop stress, 2 x 200psi=400psi.

C.4.3 Transient Parameters

The following are the transient parameters for the ESW:

Temperature: 160°F

Hoop Stress: 500psi

Duration: 30 days (U.S. EPR™ temperature excursion duration)

The hoop stress is taken as the hoop stress at the design pressure of 200psig for a DR6 pipe wall. For a Design Factor of 0.5, the LTHS used in the Rate Process Method is two times the operating hoop stress, 2 x 500psi=1000psi

C.5 Calculation Results

C.5.1 Coefficients from the Rate Process Method

The data from the Lyondell Basell regression curves can be written in the following form:

$$Log(100{,}000) = A + \frac{B}{73+460} + \frac{C \times Log(1581.05)}{73+460}$$

$$Log(100{,}000) = A + \frac{B}{140+460} + \frac{C \times Log(971.835)}{140+460}$$

$$Log(21{,}000) = A + \frac{B}{176+460} + \frac{C \times Log(797.775)}{176+460}$$

Since there are three equations and three unknown variables (A, B, and C), matrices can be used to solve the system of equations.

$$F = \begin{bmatrix} 1 & \frac{1}{T_1+460} & \frac{\log(S_1)}{T_1+460} \\ 1 & \frac{1}{T_2+460} & \frac{\log(S_2)}{T_2+460} \\ 1 & \frac{1}{T_3+460} & \frac{\log(S_3)}{T_3+460} \end{bmatrix} \qquad D = \begin{bmatrix} Log(t_1) \\ Log(t_2) \\ Log(t_3) \end{bmatrix} \qquad [F]^{-1}[D] = [H] = \begin{bmatrix} A \\ B \\ C \end{bmatrix}$$

The solution to the system of equations yields the following results for the coefficients used in the Rate Process Method:

| Rate Process Method | |
|---|---|
| A= | -42.457 |
| B= | 73419.299 |
| C= | -15043.99 |

C.5.2 Establishing the 50 year and 60 year LTHSs for Temperatures up to 160°F

This section will establish the Hydrostatic Design Basis, HDB, for HDPE 4710 material using the Rate Process Method. The variables which are used in the Rate Process Method are data points that were already established using other test methods. Using the coefficients from section C.5.1, the Rate Process Method can be used to extrapolate the regression curve out to 160°F at 100,000 hours (11.4 years).

$$Log(100{,}000hrs) = -42.457 + \frac{73{,}419.229}{160°F + 460} + \frac{-15{,}043.93 \times Log(S)}{160°F + 460}$$

Solving this equation for S, yields an HDB stress of 840.416psi. An HDB of 800psi can be used at 160°F since the calculated value, 840.416psi, is within the range for an 800psi HDB per Table 1 of ASTM D2837.

Using the Rate Process Method again for validation of this 800psi HDB per Table 7 of ASTM D2837, calculate the stress at 176°F for 37,500 hours which yields the following result:

$$Log(37{,}500hrs) = -42.457 + \frac{73{,}419.229}{176°F + 460} + \frac{-15{,}043.93 \times Log(S)}{176°F + 460}$$

where the stress, S, is equal to 779.883 psi. Per Table 7 of ASTM D2837 a stress of 779.883psi is greater than the required stress of 705psi to establish and validate an HDB of 800psi at 160°F.

Now that the HDB is established for 160°F, The Rate Process Method can be used to extrapolate this 160°F HDB from 100,000 hours (11.4 years) to 438,000 hours and 525,600 hours (to derive the 50 year and 60 year LTHSs respectively),

$$Log(438{,}0000hrs) = -42.457 + \frac{73{,}419.229}{160°F + 460} + \frac{-15{,}043.93 \times Log(S)}{160°F + 460}$$

$$Log(525{,}600hrs) = -42.457 + \frac{73{,}419.229}{160°F + 460} + \frac{-15{,}043.93 \times Log(S)}{160°F + 460}$$

These equations yield 160°F 50 year and 60 year LTHS stresses of 790.78 psi and 784.86 psi respectively.

The Rate Process Method can also be used to extrapolate the 73°F HDB from 100,000 hours (11.4 years) to derive the 73°F LTHS at 438,000 hours and at 525,600 hours (50 year LTHS and 60 year LTHS respectively),

$$Log(438{,}0000hrs) = -42.457 + \frac{73{,}419.229}{73°F + 460} + \frac{-15{,}043.93 \times Log(S)}{73°F + 460}$$

$$Log(525{,}600hrs) = -42.457 + \frac{73{,}419.229}{73°F + 460} + \frac{-15{,}043.93 \times Log(S)}{73°F + 460}$$

These equations yield 73°F 50 year and 60 year LTHS stresses of 1500.42 psi and 1490.76 psi respectively.

### C.5.3 Design Life for Normal Operation ESW @ 115°F

The following calculation uses the coefficients calculated in Section C.5.1 and the inputs from Section C.4.2, to determine the design life at normal operating pressures and temperatures.

$$Log(t) = -42.457 + \frac{73{,}419.229}{115°F + 460} + \frac{-15{,}043.93 \times Log(400\,psi)}{115°F + 460}$$

| Rate Process Method to determine the Design Life of ESW @ 115°F | | | |
|---|---|---|---|
| A = | -42.457 | | Section C.5.1 |
| B = | 73419.229 | | Section C.5.1 |
| C = | -15043.93 | | Section C.5.1 |
| T = | 115 | °F | U.S. EPR™ (COLA) FSAR Rev.2 Section 9.2.1 |
| S = | 400 | psi | LTHS from Section C.4.2 |
| t = | $1.410 \times 10^{17}$ | hrs | RPM to solve for hours |
| | $1.61 \times 10^{13}$ | years | Design Life for 115°F @ 400psi |

### C.5.4 Design Life for Temperature Excursion

The following calculation uses the coefficients calculated in Section C.5.1 and the inputs from Section C.4.3, to determine the design life at the transient temperatures.

$$Log(t) = -42.457 + \frac{73{,}419.229}{160°F + 460} + \frac{-15{,}043.93 \times Log(1000\,psi)}{160°F + 460}$$

| Rate Process Method to determine the service life @ 160°F | | | |
|---|---|---|---|
| A = | -42.457 | | Section C.5.1 |
| B = | 73419.229 | | Section C.5.1 |
| C = | -15043.93 | | Section C.5.1 |
| T = | 160 | °F | 30 Day temperature excursion |
| S = | 1000 | psi | LTHS from Section C.4.3 |
| t = | 1,469.745 | hrs | RPM to solve for hours |
| | 61.208 | Days | Design Life for 160°F @ 1000psi |

C.5.5 Design Life Determination

The calculated time to rupture is 61 days at 160°F using the hoop stress for a design temperature of 140°F (1000psi). The 30 day duration of the temperature transient uses up ½ of the design life for an event that may occur once in the 60-year plant life during which this 160°F design condition exists.

30 Day Event / 61 Day Design Life = ½ of the Design Life Used

As noted above, a pipe wall selected for the design conditions will have a much lower stress during normal operating conditions, and the pipe's design life for normal operation at 115°F is expected to exceed 1000 years (See Section C.5.3). With ½ of the design life remaining for normal operation at 115°F, the design life is 500 plus years, which exceeds the required 60 year plant life.

½ × 1000 years (Design Life @ 115°) = 500 years > 60 years required for U.S. EPR™.

C.6 Conclusions

The Rate Process Method was used to determine the design life of the service water pipe that is designed for 140°F and 200psig, with a 30 day temperature excursion of 160°F. This calculation has shown that the pipe greatly exceeds the required 60 year service life based on normal operation parameters and the transient parameters.

C.7 References

C.7.1 PPI TN-16-2008, Rate Process Method for Projecting Performance of PE Piping Components

C.7.2 ASTM D3350-2006, Standard Specification for PE Plastics Pipe and Fittings PE compounds

C.7.3 EPRI 1013549-2006, Nondestructive Evaluation: Seismic Design Criteria for Polyethylene Pipe Replacement Code Case

C.7.4 ASTM D2837-2008, Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products.

C.7.5 ISO 9080 Regression Analysis per Becetel's Standard Extrapolation Method (SEM) Software, Lyondell Basell

C.7.6 ASTM F714-08, Standard Specification for PE Plastic Pipe (SDR-PR) Based on Outside Diameter

# APPENDIX D: Certificate Requirements for Organizations Supplying, Fabricating and/or Installing PE4710

## NCA-3900 Nonmetallic Material Manufacturer's, Constituent Supplier's and Polyethylene Material Organization's Quality System Program

### NCA-3910 Applicability

Intentionally Left Blank.

### NCA-3920 Quality System Certificate (Nonmetallic Materials)

Intentionally Left Blank.

### NCA-3923 Evaluation for Quality System Certificates

Intentionally Left Blank.

### NCA-3950 Quality Program Requirements

Intentionally Left Blank.

### NCA-3960 Responsibility

### NCA-3961 Constructor or Fabricator

See Section 10.5.3

### NCA-3962 Nonmetallic Material Manufacturer

Intentionally Left Blank.

### NCA-3963 Nonmetallic Material Constituent Supplier

Intentionally Left Blank

### NCA-3970 Polyethylene Material Organization's Quality System Program

A. The requirements of NCA-3970 provide for various entities known as Certificate Holders and Polyethylene Material Organizations. Performance of operations, processes and services related to the procurement, manufacture, and supply of Polyethylene Source Material and Polyethylene Material is limited to these entities. These terms as well as other terms used in NCA-3970 are defined in Section 1.1.

B. The Polyethylene Material Organization shall obtain a Quality System Certificate issued by the Society verifying the adequacy of the applicant's Quality System Program

C. As an alternative to (b) above, the Polyethylene Material Organization shall have their Quality System Program surveyed and qualified by the holder of an ASME Certificate of Authorization with responsibility for compliance with the rules of Section III.

D. As an alternative to (b) above, the Polyethylene Service Supplier shall have its Quality System Program surveyed, and qualified by the Polyethylene Source Material

Manufacturer or Polyethylene Material Manufacturer using the services of the Polyethylene Service Supplier.

E. Subcontracting is restricted as provided in NCA-3973(b)(2).

F. When requirements of NCA-3800 are invoked, the term "Material Organization" in NCA-3800 shall apply to Polyethylene Material Organization. The term "material" in NCA-3800 shall apply to Polyethylene Material and Polyethylene Source Material. The term "source material" in NCA-3800 is not applicable.

**NCA-3971 Responsibility of Polyethylene Material Organizations**

Polyethylene Material Organizations shall be responsible for establishing a Quality System Program in accordance with the requirements of NCA-3972, 3973 and 3974, as applicable to the scope of activities performed.

**NCA-3971.1 Additional Responsibility of Polyethylene Source Material Manufacturers**

The Polyethylene Source Material Manufacturers' Quality System Program shall include the following, as a minimum:

A. Establishing and maintaining measures for the traceability of Polyethylene Source Material while under its control.

B. Controlling quality during manufacture, including control of testing, examination, and treatment of Polyethylene Source Material.

C. Evaluation of Polyethylene Service Suppliers for calibration, testing, and nondestructive examination in accordance with the requirements of NCA-3972.3.

D. Preparing Certificates of Analysis.

E. Shipment of Polyethylene Source Material.

**NCA-3971.2 Additional Responsibility of the Natural Compound Manufacturer**

In addition to the requirements of NCA-3971.1, the Natural Compound Manufacturer shall be responsible for:

A. Providing the required data including test results from a sample of Polyethylene Compound and obtaining a listing for that sample's Material Designation in accordance with Plastic Pipe Institute standards listed in Table NCA-7100-2.

B. Issuing the "Natural Compound Manufacturing and Testing Procedure."

C. Determining Pigment Concentrate Compound that, when combined with Natural Compound manufactured by the Natural Compound Manufacturer, shall produce Polyethylene Compound that complies with a material specification permitted by Section III. This shall be done by either (1) or (2), below:

1) Providing procedures to the Pigment Concentrate Compound Manufacturer for manufacture of Pigment Concentrate Compound.

2) Testing Pigment Concentrate Compound provided and identified by the Pigment Concentrate Compound Manufacturer with a specific trade name.

D. Providing documentation to the Polyethylene Compound Manufacturer and Polyethylene Material Manufacturer specifying, by trade name, Pigment Concentrate Compound that shall comply with a material specification permitted by Section III when combined with the Natural Compound manufactured by the Natural Compound Manufacturer.

E. Certifying that Natural Compound is in compliance with Section III and the "Natural Compound Manufacturing and Testing Procedure."

**NCA-3971.3 Additional Responsibility of the Pigment Concentrate Compound Manufacturer**

In addition to the requirements of NCA-3971.1, the Pigment Concentrate Compound Manufacturer shall be responsible for:

A. Issuing the "Pigment Concentrate Compound Manufacturing and Testing Procedure."

B. Manufacturing Pigment Concentrate Compound that shall comply with a material specification permitted by Section III when it is combined with Natural Compound manufactured by the Natural Compound Manufacturer. This shall be done by either (1) or (2), below:

1) Manufacture Pigment Concentrate Compound in accordance with procedures provided by the Natural Compound Manufacturer.

2) Manufacture Pigment Concentrate Compound that has been identified, by trade name, as acceptable by the Natural Compound Manufacturer.

C. Certifying that Pigment Concentrate Compound is in compliance with Section III and the "Pigment Concentrate Compound Manufacturing and Testing Procedure."

**NCA-3971.4 Additional Responsibility of the Polyethylene Compound Manufacturer**

In addition to the requirements of NCA-3971.1, the Polyethylene Compound Manufacturer shall be responsible for:

A. Issuing a "Polyethylene Compound Manufacturing and Testing Procedure."

B. Using Pigment Concentrate Compound and Natural Compound to manufacture Polyethylene Compound that complies with Section III and a material specification permitted by Section III.

C. Manufacturing and testing Polyethylene Compound in accordance with the "Polyethylene Compound Manufacturing and Testing Procedure."

D. Certifying that Polyethylene Compound is in compliance with Section III, a material specification permitted by Section III, and the "Polyethylene Compound Manufacturing and Testing Procedure."

**NCA-3971.5 Responsibility of Polyethylene Material Manufacturer**

The Polyethylene Material Manufacturer's Quality System Program shall include the following, as a minimum:

A. Establishing and maintaining measures for the traceability of Polyethylene Source Material and Polyethylene Material while under its control.

B. Issuing the "Polyethylene Material Manufacturing and Testing Procedure."

C. Manufacturing Polyethylene Material that complies with a material specification permitted by Section III. This shall be done by either (1) or (2) below:

1) Manufacturing Polyethylene Material using Pigment Concentrate Compound and Natural Compound as specified by the Natural Compound Manufacturer.

2) Manufacturing Polyethylene Material using Polyethylene Compound as specified by the Polyethylene Compound Manufacturer.

D. Manufacturing and testing Polyethylene Material in accordance with Section III, a material specification permitted by Section III, and the "Polyethylene Material Manufacturing and Testing Procedure."

E. Controlling quality during manufacture, including control of testing, examination, and treatment of Polyethylene Source Material and Polyethylene Material.

F. Evaluation of Polyethylene Service Suppliers for calibration, testing, and nondestructive examination in accordance with the requirements of NCA-3972.3.

G. Preparing Certified Polyethylene Test Reports.

H. Certifying that all Polyethylene Material is in compliance with Section III, a specific material specification permitted by Section III, and the "Polyethylene Material Manufacturing and Testing Procedure."

I. Shipment of Polyethylene Material.

**NCA-3971.6 Responsibility of Polyethylene Material Supplier**

The Polyethylene Material Supplier's Quality System Program shall include the following, as a minimum:

A. Establishing and maintaining measures for the traceability of Polyethylene Material while under its control including identification established per NCA-3971.5(a).

B. Shipment of Polyethylene Material.

**NCA-3971.7 Responsibility of Polyethylene Service Supplier**

The Polyethylene Service Supplier's Quality System Program shall include the following, as a minimum:

A. Establishing and maintaining measures for the traceability of Polyethylene Source Material and Polyethylene Material while under its control.

B. Controlling quality including control of testing, and examination of Polyethylene Source Material and Polyethylene Material.

C. Evaluation of Polyethylene Service Suppliers providing calibration, in accordance with the requirements of NCA-3972.3.

**NCA-3972 Evaluation of Quality System**

**NCA-3972.1 Evaluation by the Society (ASME)**

A. The Society will arrange for a survey of the applicant's Quality System Program for the scope of activities at the locations listed on the application. The evaluation will be conducted in accordance with the requirements of NCA-3841.

B. The Quality System Certificate that is issued, for up to a 3-year period, will describe and specify the scope and limits of work and locations for which the applicant is qualified and will be subjected to a planned audit program by the Society

**NCA-3972.2 Evaluation by ASME Certificate Holders**

A. Except for evaluation of Polyethylene Service Suppliers, evaluation by parties other than the Society shall be performed by an ASME Certificate of Authorization Holder.

B. NCA-3842.2 applies except for the following:

1) The reference in NCA-3842.2 (a) to NCA- 3850 is changed to NCA-3972, NCA-3973 and NCA-3974.

2) The NCA-3842.2 (i) allowance of performance assessments in lieu of annual audits is prohibited.

**NCA-3972.3 Evaluation of Polyethylene Service Suppliers by the Polyethylene Source Material Manufacturer or Polyethylene Material Manufacturer**

A. Evaluation of Polyethylene Service Suppliers may be performed by Polyethylene Source Material Manufacturer or Polyethylene Material Manufacturer using the service.

B. NCA-3842.2 applies except for the following:

1) The reference in NCA-3842.2 (a) to NCA- 3850 is changed to NCA-3972, NCA-3973 and NCA-3974.

2) The NCA-3842.2 (i) allowance of performance assessments in lieu of annual audits is prohibited.

**NCA-3972.4 Evaluation of Polyethylene Service Suppliers of Calibration Services by the Polyethylene Service Suppliers**

A. Evaluation of Polyethylene Service Suppliers of calibration services may be performed by Polyethylene Service Suppliers using the calibration service.

B. NCA-3842.2 applies except for the following:

1) The reference in NCA-3842.2 (a) to NCA- 3850 is changed to NCA-3972, NCA-3973 and NCA-3974.

2) The NCA-3842.2 (i) allowance of performance assessments in lieu of annual audits is prohibited.

**NCA-3973 Quality Program Requirements**

A. The Polyethylene Material Organization shall establish a Quality System Program for the control of quality during manufacture or during other work it proposes to perform, and for the traceability of Polyethylene Source Material, and Polyethylene Material under its control. The controls used in the Quality System Program shall be documented in a Quality System Manual.

B. The Quality System Program shall be planned, documented, implemented, and maintained in accordance with the requirements of NCA-3850, as applicable to the scope of activities performed except as follows:

1) NCA-3851.2(a)(6), NCA-3855.1(b), NCA- 3855.3 (a) and (b), NCA-3855.5, NCA-3856.3(b) NCA-3856.3(e), NCA-3856.4, and NCA-3857.3 do not apply and those activities are prohibited. Provisions of NCA-3855.3 (c) shall be limited to calibration services

2) Any subcontracting shall be to Polyethylene Service Suppliers. Subcontracting is allowed for testing, nondestructive examination and calibration. Subcontracting of operations that affect compliance with the procedures, material property, and design requirements of Section III is prohibited.

3) Repair is prohibited.

4) When design of Polyethylene Material is within the scope of activities, design controls shall comply with the requirements of ASME NQA-1, Quality Assurance Requirements for Nuclear Facilities, Basic Requirement 3 and Supplement 3S- 1. The applicable version of NQA-1 shall be in accordance with Table NCA-7100-2.

5) Audits shall include a review of the implementation of all elements of the Quality System Program at the location of the work and shall be conducted at least annually.

6) The "approved supplier" mentioned in NCA- 3800 is not applicable and not allowed.

7) Polyethylene Material Organizations are only allowed to qualify Polyethylene Service Suppliers. Polyethylene Service Suppliers are only allowed to qualify Polyethylene Service Suppliers performing calibration services.

8) Polyethylene Material shall be permanently marked with the following, as a minimum:

   a. Polyethylene Material Manufacturer's company name.
   b. Polyethylene material specification as permitted by Section III.
   c. Polyethylene Compound designation as listed in Plastics Pipe Institute TR-4 (Table NCA 7100-2).

d. A lot number defined and described in the Polyethylene Material Manufacturer's Quality System Manual and the Certified Polyethylene Test Report that identifies the following information:
   (1) The Polyethylene Source Material(s);
   (2) The location of manufacture;
   (3) The production equipment and personnel or shift;
   (4) The date of manufacture.

e. Markings (a) thru (d) may be abbreviated in trademarks or codes provided the trademarks or codes are defined and described in the Polyethylene Material Manufacturer's Quality System Manual and the Certified Polyethylene Test Report or an identified attachment to the Certified Polyethylene Test Report.

9) Identification of Polyethylene Source Material shall be by marking the containers or tags attached to the containers and shall include the following, as a minimum:

   a. Polyethylene Material Manufacturer's company name.
   b. Polyethylene Source Material designation as listed in Plastics Pipe Institute TR-4 (Table NCA- 7100-2).
   c. Location of manufacture.
   d. Lot number identifying the Polyethylene Source Material.
   e. Markings (b) thru (d) may be abbreviated by a unique code on the shipping container provided the codes are defined and described in the Polyethylene Material Manufacturer's Quality System Manual and the Certified Polyethylene Test Report.

10) Certificates of Compliance are not applicable.

11) Welding and heat treatment are not applicable.

**NCA-3974 Certification Requirements**

**NCA-3974.1 Certificates of Analysis**

The Polyethylene Source Material Manufacturer shall provide a Certificate of Analysis.

A. The Certificate of Analysis shall include Polyethylene Source Material identification as required by NCA-3973(b)(9), actual test and examination results and any other required certifications.

B. A certification shall be included that affirms that contents of the Certificate of Analysis are correct and accurate and that all test results and examinations performed by the organization and its subcontractors are in compliance with Section III and specified requirements.

C. Required Certificates of Analysis shall be transmitted at the time of shipment.

**NCA-3974.2 Certified Polyethylene Test Reports**

The Polyethylene Material Manufacturer and Polyethylene Material Supplier shall provide a Certified Polyethylene Test Report for Polyethylene Material.

A. The Certified polyethylene Test Reports shall include Polyethylene Material identification as required by NCA-3973(b)(8), actual test and examination results and any other required certifications.

B. A certification shall be included that affirms that contents of the report are correct and accurate and that all test results and operations performed by the organization and its subcontractors are in compliance with the material specification and the specific applicable requirements of Section III.

C. The Polyethylene Material Manufacturer shall also certify that the Polyethylene Material conforms to the applicable dimensional requirements.

D. The Polyethylene Material Manufacturer and Polyethylene Material Supplier shall transmit all required Certified Polyethylene Test Reports including Certificates of Analysis from the Polyethylene Source Material Manufacturer at the time of shipment.

**NCA-3974.3 Additional Certification Requirements**

A. The Certified Polyethylene Test Report shall include the actual results of all required physical and mechanical property tests. A certification that the Polyethylene Source Material used were made from virgin polyethylene, not scrap or regrind Polyethylene Material, shall also be included.

B. When required tests or nondestructive examinations are subcontracted, the approved Polyethylene Service Supplier's certification for the operations performed shall be furnished as an identified attachment to the Certified Polyethylene Certified Test Report.

C. When operations other than tests or nondestructive examinations that require maintenance of traceability are subcontracted, these operations and the approved Polyethylene Service Supplier performing them shall be listed on the Certified Polyethylene Test Report, or the approved Polyethylene Service Supplier's certification for the operation may be furnished as an attachment to the Certified Polyethylene Test Report. Operations that affect design or properties of the Polyethylene Source Material, and Polyethylene Material shall not be performed by Polyethylene Service Suppliers.

D. Reporting of actual dimensions and visual examination results is required

E. Polyethylene Material identification shall be described in the Certified Polyethylene Test Report.

**NCA-3974.4 Quality System Program Statement**

A. When the Polyethylene Material Organization holds a Quality System Certificate, the organization's Quality System Certificate number and expiration date shall be shown on the Certificate of Analysis and Certified Polyethylene Test Report.

B. When the organization has been qualified by a party other than ASME, the identification, revision and date of the applicable Quality System Manual shall be shown on the Certificate of Analysis and Certified Polyethylene Test Report.

C. The inclusion of the Quality System Certificate number and expiration date or reference to identification, revision and date of the applicable Quality System Manual shall be considered the organization's certification that all activities have been performed in accordance with the applicable requirements of Section III.

**NCA-4100 Requirements**

**NCA-4110 Scope and Applicability**

A. This sets forth the requirements for planning, managing, and conducting Quality Assurance Programs for controlling the quality of activities performed under this Section and the rules governing the evaluation of such Programs prior to the issuance of certificates for the construction, fabrication, manufacture, and installation of Class 3 items. The Quality Assurance requirements for Metallic Material Organizations for all Classes of construction are provided in NCA-3800. The Quality Assurance requirements for Nonmetallic Material Organizations, Polyethylene Material Organizations and Constituent Suppliers for all Classes of construction are provided in NCA-3900. Certificate Holders are advised to consult other regulations for Quality Assurance requirements governing activities beyond the scope of this Section.

B. N-Type Certificate Holders shall comply with the Basic Requirements and Supplements of ASME NQA-1–1994 Edition, Quality Assurance Program Requirements for Nuclear Facilities, as modified and supplemented in NCA-4120(b) and NCA-4134.