Nuclear Energy Standards Coordination Collaborative

Polymer Piping Codes and Standards for Nuclear Power Plants

Current Status and Recommendations for Future Codes and Standards Development

2013

NIST National Institute of Standards and Technology • U.S. Department of Commerce

ANSI American National Standards Institute

Nuclear Energy Standards Coordination Collaborative

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Polymer Piping Task Group

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Preparation of this Report

This report was prepared by the NESCC Polymer Piping Task Group (PPTG). Membership on the PPTG was open. Efforts were made to include representatives from standards development organizations (SDO), nuclear plant operators and design, and polyethylene piping manufacturers that are involved in nuclear power plant construction.

Convener: The Convener of the PPTG was Aaron M. Forster, Engineering Laboratory, National Institute of Standards and Technology, Gaithersburg (USA)

The table below lists the organizations and their representatives that participated in the PPTG:

	Name		**Title**	**Company**
	Last	First		
1	August	James	VP Technical Operations	Core Inc.
2	Thompson	David	Director, Standards and Publications	Manufacturers Standardization Society (MSS)
3	Boros	Stephen	Technical Director	Plastics Piping Institute
4	Clark	Mark		Nibco, Inc.
5	Rowley	Wes	Vice President	Wesley Corporation
6	Focht	Eric	Materials Engineer	US Nuclear Regulatory Commission Office of Nuclear Regulatory Research
7	Forster	Aaron	Materials Engineer	Engineering Laboratory NIST
8	Mason	Jim		Mason Materials Development, LLC
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11	Lefler	Steven	Principal Engineer	Duke Energy
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16	Svetlik	Harvey	Director of Engineering and QA Systems	Independent Piping Products, Inc.
17	Wheeler	Larry	Reactor Systems Engineer	US Nuclear Regulatory Commission Office of New Reactors Division of Safety Systems and Risk Assessment
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1 Introduction

The Nuclear Energy Standards Coordination Collaborative (NESCC) is a joint initiative of the American National Standards Institute (ANSI) and the National Institute for Standards and Technology (NIST) to identify and respond to the current needs of the nuclear industry. NESCC was created in June 2009. More details on NESCC and its activities can be found at: (http://www.ansi.org/standards_activities/standards_boards_panels/nescc/overview.aspx?menuid=3).

In July 2010, NESCC formed a task group "Polymeric Piping for Nuclear Power Plants Task Group", referred to as the "Polymer Piping Task group" (PPTG) in this report. The request (Appendix A) for the formation of the task group had the following scope:

- Establish coordination and consistency of safety and non-safety related polymer piping requirements in nuclear power plants;
- Identify and review all NRC regulatory documents related to polymeric piping for nuclear power plants;
- Identify and review all ASTM, ASME, AWWA, ISO and PPI standards related to polymeric piping water applications;
- Identify ancillary standards needed to certify manufacturers and the installation and inspection of piping

The scope, as presented at the NESCC meeting, was considered similar to task groups currently operating within ASME to address Boiler and Pressure Vessel code development issues and piping systems standards development issues. The convener of the PPTG held a meeting at the ASME code week in Washington D.C. with ASME members. The goal of this meeting was to develop a task group scope that was synergistic with ASME efforts and would meet the needs of the NESCC. The scope was expanded to the following:

- Conduct a survey of current ASTM, ASME, AWWA, ISO, and PPI standards related to HDPE piping.
- Comment on the applicability of each HDPE piping and fitting standard to current and future applications in the nuclear industry. The focus would be on the use of polyethylene material in ASME Code Class 3 piping applications for NPPs.
- Identify existing gaps in HDPE piping standards for nuclear applications.
- Identify a reasonable mechanism and time frame to fill identified gaps.
- Develop a 5 to 10 year roadmap for the application of HDPE piping in safety related nuclear applications and the anticipated standards needs.

The initial membership was determined from an open call to the ASME community and an announcement by the NESCC. The membership remained open to new members over the course of developing the PPTG report. The group met by virtual meetings regularly, and a face-to-face at the ASME Code Week. Each member was asked to contribute on topics related to their expertise and to review the report during meetings. In between meetings, a formal vote was conducted to ensure that the concerns of all members were addressed in the next version of the report. As of 2012, **3** ballots were conducted by e-mail. Each time a report and a ballot form were sent to members and reviewers. The comments were, as assigned by the voter, either **Primary (P)** comments to identify technical issues, or **Editorial (E)** comments to identify editorial issues. Voters were required to provide references or provide justification for **P** comments. The ballots were returned to the Convener to organize and update the report. **P** comments were addressed by the group for clarification. The Convener addressed the E comments directly. After each ballot, a new report in track changes was sent to the members to address the primary comments. It should be noted that this report is limited to discussion of non-metallic piping, specifically polyethylene.

2 Objectives and Overview

Stakeholders, manufacturers, designers, installers, utilities, and utilities, require up to date construction standards and codes for polyethylene piping. When these are in place, it is possible to design, fabricate, install, operate, and maintain a piping system safely for the design life of the system. In addition, standards and codes should provide a methodology to safely account for changes in the operating environment over the lifetime (40 to 60 years) of the system. The overall objective of the report is to identify gaps within the current polyethylene standards that hinder the standard and code acceptance for polyethylene piping for nuclear power plant safety water applications. This is a slightly different process than the code development that occurs within ASME and accepted by the NRC, but these gaps in codes and standards should inform the code process as to areas of improvement. In addition, the scope of the task group analysis goes beyond addressing pure metrology and methodology improvements to include gaps related to utility and regulatory concerns. Therefore, the objective of this report is to identify standards gaps that will achieve the goal of polyethylene piping acceptance for safety water applications in nuclear power plants.

With this focus, the PPTG decided that a comprehensive review of all non-metallic (thermoplastic, thermoset, and composite) standards would be cumbersome and difficult to compile within one report. The specific polyethylene (HDPE) standards for ASME BPV Code Case N-755 may be found in Table III-I of the Mandatory Appendix III. Indeed, even a focus only on polyethylene standards would be extensive. Three other sources have developed substantial lists of polyethylene standards in the U.S. and globally. The source for U.S. standards for polyethylene and thermoset piping materials was provided by the ASME working group on non-metallic materials and is reproduced in Appendix B from their charter document. The second source has been developed and published by the Plastics Piping Institute (PPI). This document is TR-5/2010 "Standards for Plastics Piping" and it is an extensive list of standards related to plastic piping. The source for global standards concerning polyethylene was found at The Welding Institute (TWI) in the U.K. This list may be found under the Standard FAQs link under the Standards for Polyethylene Piping: (http://www.twi.co.uk/services/technical-information/faqs/standards-faqs/faq-standards-used-for-polyethylene-piping/).

The task group decided to focus on the current gaps within the polyethylene piping ASME BPV N-755 (2012) Code Case process, as this is a focused goal for deriving a gap analysis. HDPE has been the guiding material through ASME BPV Code Case N-755 and much work remains to finish the process. Therefore, this material can serve as a template for additional thermoplastic materials that seek approval and relief requests for nuclear safety water applications. In order to provide completeness, the task group has excerpted a section of the technical plan from the ASME working group Non-Metallic Materials. This section provides an overview of ASTM standards for material property measurements of thermoplastic, thermoset, and composite piping and is located in Appendix B. The ASME created a new Committee for Nonmetallic Piping Systems in 2012; it has three subcommittees (SC on Thermoplastics, SC on Thermoset Plastics, and SC on Nonmetallic Materials). The SC on Thermoplastics is concentrating on polyethylene piping systems, where "Piping systems" includes piping, tanks, vessels, pumps, and valves. The application of HDPE piping standards generally follows four categories that the PPTG has tried to adhere to in the layout of this gap analysis. These categories are:

- Standards for the polyethylene resin pellets
- Standards for the quality assurance of piping produced from the resin
- Standards for the industrial application such as nuclear, gas, or water
- Standards for long-term performance, degradation, or disaster resilience of the piping

Five objectives were given to the PPTG as defined in Section 1. A short summary is given here along with a clarification of objectives and references to the appropriate sections.

1. *Conduct a survey of current ASME, ASTM, AWWA, ISO, PPI, and ancillary standards related to polyethylene piping and fittings.*

2. *Comment on the applicability of each piping and fitting standard to current and future applications in the nuclear industry. This includes non-safety and safety related applications.*

3. *Identify existing gaps in piping standards for nuclear applications.*
   The report is composed of sections that address a specific structure or procedure related to piping that is governed by specific standards. Objectives 1 - 3 are combined together within the individual sub-sections of Section 5. The standards related to each section are discussed in the following manner:

   Title of Standard
   a) *Status today*
   b) *What needs to be changed for application to a nuclear power plant?*
   c) *Why does the standard need to be changed?*
   d) *Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it inhibit the wide application of a specific material or structure class to the nuclear industry?*

4. *Identify a reasonable mechanism and time frame to fill identified gaps.*
   In Section 6, priority is given to critical gaps and those where a reasonable mechanism exists to fill the identified gaps in a reasonable time frame. In this section the PPTG provided input as to which entity or combination of entities may be best suited to facilitate closing an identified gap. These entities include: standards development organization (SDO), piping or resin manufacturer, utilities, regulatory, academic, and governmental institutions.

5. *Develop a 5 to 10 year roadmap for the application of polyethylene piping in non-safety and safety related nuclear applications; including ancillary and anticipated standards needs.*
   In Section 7, the PPTG has organized a roadmap to generally address where standards for HDPE materials should be used in the next decade to maximize the benefit to the nuclear industry. This was done to provide guidance to the NESCC on the future outlook for this class of materials and to anticipate standards coordination concerns before they become critical.

There are two types of gaps that may be identified when evaluating a standard. The first gap (a process gap) identifies a missing measurement technique, experimental control, or technology application to address a need of the nuclear industry. The second gap (a specification gap) is related to additional performance requirements to qualify a material or piping system for nuclear plant applications. Specification gaps are not critical for the success of the standard. In the case of the nuclear industry, additional performance qualifiers are often placed within the ASME BPV code to fill the specification gap. This has the advantage of leaving the reference standard relatively uncluttered with nuclear specific requirements and available to other industries such as gas or water. The disadvantage is a reduction in efficiency for the nuclear industry since two sources (the code and the standard) are required for material specification/application. The PPTG has tried to minimize the identification of gaps related to the specification gap, but in certain cases the number of additional requirements is significant compared to the reference standard. In these cases, the PPTG included both process and specification gaps in Section 6 to help identify instances where amplifications were added to the ASME BPV Code Case N-755. The PPTG has also identified several definitions that will aid in understanding the standards gaps identified within the report and the need of the nuclear industry for HDPE piping.

3 Definitions and Operational Needs

Nuclear utilities in the United States have replaced or are replacing buried service water lines with bimodal high density polyethylene (HDPE) materials. Currently, there are no other polymer-based materials used in buried service water systems that are classified as Class 3 by ASME. In above ground applications for nuclear facilities, the number of materials that have been used or are currently being used is still being assessed[1].

Essential service water is the heat sink used in the active cooling system of nuclear plants in the case of a design basis accident among other components required to generate power. For example, service water cools emergency diesel generators that supply emergency power for the continued operation of important plant equipment in the event of loss of offsite power. In some cases, it is convenient to continuously run the service water system at a lower pressure and temperature for basic plant operations, but the system is capable of handling higher pressure, temperature, and flow in the case of an accident. Safety related systems in a nuclear power plant typically have at least two 100% capacity trains to deliver the design specified fluids.

There are several definitions that are relevant to discussing piping in nuclear power plant applications. These definitions will be presented in order to frame the discussion of the different standards that are related to the piping system in nuclear power plant applications.

Safety Related: Safety-related structures, systems and components means those structures, systems and components that are relied upon to remain functional during and following design basis events to assure:

(1) The integrity of the reactor coolant pressure boundary

[1] Sizewell B in England installed HDPE for plant safety related service water piping using ASME B31.1 Power Piping Code in 2005. Code Case N-155-2 provides the requirements for thermoset piping (fiber-glass spiral wound epoxy piping). The PPTG did not address this code case in reviewing standards for polyethylene piping.

(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 which could result in potential offsite exposures comparable to the applicable guideline exposures set forth in §50.34(a)(1) or §100.11 of this chapter, as applicable.[2]

The standards and design code for safety related polyethylene piping that fits into the above description are currently addressed within ASME Code Case N-755.

Non-Safety Related: This is all other power plant piping standards and the design code covered by or related to ASME B31.1 code. Examples of this type of piping in a nuclear plant include cooling water provided for heat exchangers, pump bearings, air compressor and motor cooler equipment associated with the conventional steam power plant equipment.

Underground Piping: Piping that is located below grade such as buried piping and piping located in covered trenches.

Buried: Piping that resides underground and covered by backfill.

Above ground: Piping that resides above ground whether exposed to outdoor environment or within an environmentally controlled building.

Operating Conditions: Conditions of temperature, pressure, and time that the piping is expected to safely perform in the nuclear plant.

Standard: a protocol set up and established by authority as a rule for the measure of quantity, weight, extent, value, or quality.

Design: The structure or form of a piping (pipe, fitting, valve, flange, or fusion) developed to safely operate at a set operating condition for a set design life.

Hydrostatic Design Basis (HDB): The term HDB refers to the categorized long-term hydrostatic strength (LTHS) in the circumferential or hoop direction, for a given set of end use conditions, as established by ASTM Test Method D 2837[3].

Hydrostatic Design Stress (HDS): The estimated maximum tensile stress the material is capable of withstanding continuously with a high degree of certainty that failure of the piping will not occur. This stress is circumferential when internal hydrostatic water pressure is applied[3].

Operational needs for power plant piping

[2] NRC Regulations Part 50 "DOMESTIC LICENSING OF PRODUCTION AND UTILIZATION FACILITIES".

[3] ASTM D2837-08 *Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Piping Materials or Pressure Design Basis for Thermoplastic Piping Products* ASTM International, 2008

This section categorizes needs for buried service water piping outlined through the ASME Code Case N-755 process[4].

Information on operating conditions:

1. Operating temperatures up to 175 °F (79 °C)for 30 days in an emergency event.
2. Nominal operating temperatures not to exceed 140 °F (60 °C), although it is not typical to have a constant elevated temperature. These temperatures depend on intake water temperatures, which are seasonally dependant, and the heat load transferred to the outlet via plant heat exchangers. The typical minimum operating temperature is 50 °F[5].

Information required for design:

3. Determination of tolerable flaw size based on piping dimension ratio (DR), pressure, and temperature. This includes surface and sub-surface flaws.
4. The apparent modulus of elasticity of HDPE as a function of temperature, pressure, and time.
5. Standardized sizes for valves and fittings fabricated or molded.
6. Availability of long term creep data for design of piping systems.
7. Models for quantitative service life prediction for parent material and joint that account for temperature, stress, and tolerable flaw size.

Information on standards needs:

1. A standard that describes essential variables, performance demonstrations, and fusion qualifications needed for fusion operators, equipment, and procedures.
2. Standard test method for slow crack growth resistance of butt fusion joint.
3. NDE (surface and volumetric) test standards to qualify measurement resolution and sensitivity limits and errors associated with each non-destructive technique.
4. Standards to qualify performance of valves and fittings in HDPE piping systems.
5. Fire and seismic standards for implementation of above ground installations.
6. Standard test methods for quantitative service life prediction

These needs do not represent guidance from the PPTG on the acceptability of HDPE for nuclear service water applications. In addition, this list may not represent every need that exists for polyethylene piping applications within power plants. The report has been organized to reflect the current attention of the nuclear industry on buried ASME Class 3 piping. . The body of the report addresses standards for HDPE piping materials (Section 5) and is focused on safety-related applications described in ASME BPV Code Case N-755.

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4 "Formal Response to NRC Concerns with ASME Code Case N-755", Rev. A; ASME B&PV Section III Special Working Group on Polyethylene Piping (2009)

5 Future applications of HDPE above ground, in certain climates, would require performance below the current minimum temperature. In that case, standards for rapid crack propagation that were not addressed as gaps in this report should be visited.

Applications not specifically declared in the code case, but immediately relevant to safety applications are discussed in the Gap analysis section.

4 Standards Development Organizations and Nuclear Construction Codes

The NESCC scope of work was limited to the survey of a few SDOs, but the PPTG incorporated other SDOs related to piping. This section provides a brief outline of the standards determining organizations that are involved in piping materials and ancillary systems or components. The standards developed by these organizations were reviewed in the application sub-sections of this document.

American Society of Mechanical Engineers (ASME International) - ASME is a not-for-profit professional organization that develops codes and standards relevant to piping in nuclear reactors. The main document is the Boiler and Pressure Vessel code, which is developed through voluntary consensus. This is an ANSI accredited organization.

ASTM International (ASTM) – ASTM International develops international standards based on voluntary consensus. This is an ANSI accredited organization.

International Organization for Standardization (ISO) – ISO is an international consensus based standards developer. Country membership includes 163 National institutes and industry experts.

The following organizations also produce standards related to plastic piping:

American Water Works Association (AWWA) – AWWA is a non-profit professional organization focused on the improvement of water quality and supply. AWWA publishes standard practice and testing articles for drinking and wastewater applications. This is an ANSI accredited organization.

Manufacturers Standardization Society (MSS) – MSS is a non-profit technical association organized for development and improvement of industry, national and international codes and standards for Valves, Valve Actuators, Piping Fittings, Valve Modification, Flanges, Piping Hangers, and Associated Supports. This is an ANSI accredited organization.

Plastics Piping Institute (PPI) – Trade association representing the plastic piping industry, in particular polyethylene piping. PPI develops technical literature and methodologies to determine the long-term strength of thermoplastics for piping applications. These reports may be used for the development of voluntary consensus standards by other standards developing organizations.

Uni-Bell – Trade association representing the PVC piping industry. Uni-Bell develops technical literature and methodologies to determine strength and lifetime of PVC piping.

These reports may be used for the development of voluntary consensus standards by other standards developing organizations.

Plastic Piping and Fittings Association (PPFA) - National trade association comprised of member companies that manufacture plastic piping, fittings and solvent cements for plumbing and related applications, or supply raw materials, ingredients or machinery for the manufacturing process.

FM Global (FM Approvals) - FM Global provides comprehensive global commercial and industrial property insurance, engineering-driven underwriting and risk management solutions, property loss prevention research and prompt, professional claims handling. As a function of assessing risk for underwriting, industry much meet FM Approval standards. These approval standards may reference voluntary consensus standards developed through other SDOs.

Underwriters Laboratories (UL) – UL is a global independent safety science company offering expertise across five key strategic businesses: Product Safety, Environment, Life & Health, Verification Services and Knowledge Services. One component of this expertise is fire resistance and safety of materials and products.

5 Review of Current Standards

5.1 Standards for Piping Resins

ASTM D3350 Standard Specification for Polyethylene Plastics Piping and Fittings Materials

a) *Scope and Status today*
Current edition approved Jan. 1, 2010 and published February 2010. Original approval in 1974. D3350 is a broad standard used to classify and identify the basic properties of HDPE resins intended for pressure and non-pressure piping applications. The standard does not differentiate between pressure and non-pressure applications. The scope of D3350 is broader than applies to the narrow specification of nuclear plant piping.

b) *What needs to be changed for application to a nuclear power plant?*
Amendments to ASTM D3350 or a development of a new standard for nuclear applications are needed to tailor the end-user requirements from a nuclear power plant perspective to the new requirements for the nuclear water piping application. These include, but are not limited to; extension of failure time for Pennsylvania Edge Notch Test (PENT), limits on maximum stress with elevated temperature, specifications on carbon black content, and restrictions on piping composition to one resin lot.

Since these resins will be used in HDPE piping that will be subjected to long term elevated temperature testing, it should be considered whether this standard should include the measurement of thermal degradation through Oxidation Induction Temperature (OIT) rather than induction time (IT) specified in ASTM D3350 measurements of thermally aged samples. OIT is an isothermal technique that is specified within ASTM D3895-07[6] that has been accepted within the HDPE community for evaluating relative effectiveness of anti-oxidant ingredients in HDPE compounds. Guidelines may need to be established for thermal oxidation that are acceptable and meaningful to nuclear applications.

c) *Why does the standard need to be changed?*
How to select the specific requirements from ASTM D3350 remains an issue to be solved for nuclear piping. The requirements in ASTM D3350 are based on the average of many measurements over several lots, where as nuclear applications focus on individual lots of resin materials. ASME Code Case N755 has increased material and performance requirements for nuclear HDPE resin, which are not reflected in this current standard, but they have been placed in the code case.

d) *Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it inhibit the wide application of a specific material or structure class to the nuclear industry?*
Polymer piping for use in nuclear power plants has occurred only within the last 20 years in the United States. HDPE materials property specification is more complicated given the semi-crystalline and viscoelastic nature of polyethylene material. In the past 50 years, many HDPE piping standards, specifications, codes and regulations have been developed to ensure the success of a HDPE piping system for gas, industrial and municipal water applications as provided in ASTM D3350. Resin property characteristics are critical for controlling performance[7] in the field and the ability for a utility or piping manufacturer to specify a high performance HDPE resin at the onset is critical to the successful long-term performance of HDPE piping in nuclear piping applications. Since HDPE piping is relatively new to the nuclear industry, the existing standard has specification gaps and regulatory needs

[6] ASTM D3895-07 *Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry* ASTM International
[7] Davis, P; Burn, S; Gould, S; Cardy, M; Tjandraatmadja, G; Sadler P; *Long Term Performance Prediction for PE Pipings*; AWWA Research Foundation, Denver Colorado 2007

concerning operation at elevated temperature and pressure. Currently, these have been hard coded into ASME Code Case N-755.

OIT has been utilized in the water and gas industry, but has not been used to identify degradation performance of nuclear resins that have been subjected to elevated temperature exposure beyond the current requirements of ASTM D3350. Research and specification is required to identify the proper thermal stabilizer performance and measurement method to evaluate the resiliency of nuclear HDPE resins in their expected operating environments. This research should include the development of an oxidation indication test that is indicative of both short and long-term performance of the HDPE resin.

5.2 Standards for Design Basis and Strength Requirements

ASTM D 2837, "Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Piping Materials or Pressure Design Basis for Thermoplastic Piping Products"

a) *Scope and Status today*

In the United States and most of North America, the standard methodology to determine and categorize the long-term hydrostatic strength (LTHS) of a thermoplastic material for a piping application, or thermoplastic based composite piping, is ASTM D 2837. A corollary used in other parts of the World is ISO 9080, "Plastics piping and ducting systems – Determination of the long-term hydrostatic strength of thermoplastics materials in piping form by extrapolation". Both methods are similar in their approach, but differ in assumptions made and criteria to arrive at a long-term strength value. These differences are discussed further in Section 5.5 "Long Time Performance Standards for Piping".

In addition, the Hydrostatic Stress Board (HSB) of the Plastics Piping Institute (PPI) has developed polices that utilize ASTM D2837 as the basis, along with other requirements as needed, to provide recommendations of the Hydrostatic Design Basis (HDB) as well as a recommended maximum Hydrostatic Design Stress (HDS) for the material when used in a piping application. These requirements are in the PPI Technical Report TR-3, "Policies and Procedures for Developing Hydrostatic Design Basis (HDB), Hydrostatic Design Stress (HDS), Pressure Design Basis (PDB), Strength Design Basis (SDB), and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Piping."

These HDB and HDS values are published in PPI Technical Report TR-4, "PPI Listings 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 Piping", and are required by some code bodies and recognized by many standard and certification agencies.

b) *What needs to be changed for application to a nuclear power plant?*
The methodology in ASTM D2837 used to determine the HDB for a thermoplastic compound is not application specific. It is applicable to nuclear power plant applications, but there are subtle differences between this technique and ISO 9080 that will be discussed in Section 5.5 "Standards for Long Term Performance of Polyethylene".

ASME Code Case N-755 (rev. 1) requires an increased level of performance and will only allow the highest performing PE compounds. This higher level of performance includes a 73° F HDB of 1600 psi and HDS of 1000 psi, as well as a 140 °F HDB of 1000 psi as listed in PPI TR-4. The code case further limits the maximum allowable stress values by assigning a design factor (DF) of 0.5. This design factor is more conservative DF than the 0.63 currently used in PPI TR-4[8]for these grades of polyethylene compounds. How the current conservative design factor accounts for the impact of temperature and pressure excursions above the HDB and HDS of the piping system should be investigated further.

Currently, the ASME Code Case N-755 (rev. 1) limits the application of the allowable stress values to a 50 year time period. Traditionally, HDS values are considered time independent. The 50 year limit imposed by the code case should be investigated in order to determine whether HDS (i.e. allowable stress) is time independent for nuclear water applications, and whether the potential service life, or design life, of HDPE piping systems under the code case design parameters are considered limited to a specific time frame. These should be reflected as amendments to the classification system of a nuclear piping material in ASTM D2837 and published in PPI TR-4 since this does not reflect the potential service life of the piping. The development of long-term performance predictions using ASTM D2837 will be addressed in Section 5.5 "Standards for Long Term Performance of Polyethylene".

[8] TR-4/2010/HDB/HDS/SDB/PDB/MRS Listed Materials; Plastic Piping Institute, Irving, TX 2010

c) *Why does the standard need to be changed?*

The standard currently reflects the design of HDPE piping for lower temperature and pressure water applications. The decrease in the maximum stress allowable values (HDS) is a reflection of the desire for a greater design margin for safety applications in nuclear installations vs. a "non-safety" installation. ASME Code Case N-755 uses a conservative 0.5 design factor applied to the HDB for safety applications. These changes are not reflected in the ASTM D2837, which does not provide design factor recommendations. While the design factor is conservative, the impact of temporary temperature and pressure excursions on long-term HDB are not directly considered.

d) *Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it inhibit the wide application of a specific material or structure class to the nuclear industry?*

There are two gaps mentioned for ASTM D2837; the lower HDS values through a lower design factor of 0.5 and limit of a 50 yr applicability of the allowable stress values. These gaps are not critical, but should be addressed because they will require revisiting for new piping components and resins. These gaps are the result of the nature of safety-related water piping and the need to maximize the design margin when operating at elevated temperature and pressure in these systems. There is no accepted standard to account for creep that may occur during short-term temperature or pressure excursions above the HDB or HDS. Utilities should determine whether these excursions are a significant occurrence during the 60 yr life of a nuclear power plant in order to justify additional research.

These gaps remain due to a lack of materials research combined with available empirical data. The development of elevated temperature creep data and rate-process-method models for nuclear grade resins for both ductile and brittle failure will support HDB and HDS values. This data would also provide a methodology to identify the lifetime of piping as a function of temperature and stress in order to extend the design lifetime. Power plants are licensed for 40 years with relicensing up to 20 additional years. The use of validated and tabulated empirical data obtained through the gas industry and water industry historical experience with HDPE piping should be used to develop a basis for the design factor. A full discussion of this gap will be addressed in Section 5.5 "Standards for Long Term Performance of Polyethylene".

5.3 Standards for Valves and Fittings

a) *Scope and Status today*

There are no HDPE fitting standards that presently exist for fittings used in nuclear power plants. ASTM F2880-11a "Standard Specification for Lap-Joint Type flange Adapters for Polyethylene Pressure Piping In Nominal Piping sizes ¾ in. to 65 in." has been approved for use in 2011. There are several work groups that have been started within ASTM in 2011 to address standards for numerous types of fittings.

In regard to plastic bodied valves, standards exist for the design and rating of thermoplastic valves used in the natural gas industry. ASME B16.40 has a description of the design requirements for these valves for buried use in the gas industry. There are currently two efforts underway in ASME to address standards and codes for plastic bodied valves and fittings under the B16 process.

b) *What needs to be changed for application to a nuclear power plant?*

Standards are needed for a wide range of fittings that include molded elbows, mitered elbows, tees, wyes, saddle fittings, reducers and socket electrofusion couplings. These fittings may be manufactured using either molding or fabricated (composed of fused joints). Fitting standards need to include manufacturing requirements, dimensional information, tolerances, marking, information needed for procurement, workmanship requirements and requirements for testing to verify pressure rating and lifetime of fitting.

Plastic bodied valve design standards for the gas industry do not extend to the piping diameters, design temperatures and pressures required for nuclear applications. For example, the maximum diameter and pressure specified in ASME B16.40 is 6 inches and 100 psig at the HDB design temperature, respectively. Temperature derating tables have been provided in ASME B16.40 for PVC, CPVC, PP, and PVDF valves, unions, and flanges up to 280 °F, but these tables need to be adapted to PE materials. ASME Code Case N-755 has provided temperature derating tables for HDPE piping (Table 3210-3, 3220, and 3223-3), but these tables would need to be adapted to specific fittings and construction methods including ASTM F2880-11a.

In general, conservative values are used for temperature and strength derating. These values are used to derate the HDS/HDB of piping and piping fusions developed in ASTM D2837 under long-term testing. There are no specific standards to address the long-term performance and modeling of fusion joint performance under the complex stresses experienced in a fitting in order to derate a fitting based on fitting design.

Two ancillary standards exist for the certification of small diameter (nominal size 12 and smaller) plastic valves, which are the following:

- ASTM F1970; Specification for Special Engineered Fittings, Appurtenances or Valves for use in Poly (Vinyl Chloride) (PVC) or Chlorinated Poly (Vinyl Chloride) (CPVC) Systems
- MSS SP-122; Plastic Industrial Ball Valves

There are several work items within ASTM to address the additional fitting standards. The scope of these standards will include materials and piping specifications, fusion and molding procedures, and design equations to specify the dimensions of the various fittings.

- F17.10.11.18; Standard Specification for Miter-Bends (Elbows) Fabricated by Heat Fusion Joining Polyethylene Pressure Piping Segments using Nominal Piping Sizes 2-inch to 65-inch.
- F17.10.11.19; Polyethylene Reducing Tee Massive Base Branch Saddles (MBBS) for Outlet Diameters in Nominal Piping Sizes 2-inch to 36-inch, for Sidewall Heat-Fusion to Polyethylene Piping Mains.
- F17.10.11.20; Mechanical Joint (MJ) Adapters for Polyethylene Pressure Piping in Nominal Piping Sizes (NPS) 2-inch to 60-inch (63mm to 1524mm).
- F17.10.11.21; End Caps for Polyethylene Pressure Piping in Nominal Piping Sizes (NPS) 2-inch to 54-inch (63mm to 1372mm).
- F17.10.11.23; Equal Outlet Piping Tees Fabricated by Heat Fusion Joining Polyethylene Pressure Piping Segments of Nominal Piping Sizes (NPS) 2-inch to 65-inch (63 mm to 1651mm).
- F17.10.11.24; Piping WYES Fabricated by Heat-Fusion Joining Mitered Polyethylene Piping Segments of Nominal Piping Sizes (NPS) 2-inch to 65-inch, using Flat Heater Plates.

c) *Why does the standard need to be changed?*

Development of fitting and plastic bodied valve standards would facilitate design, procurement, and installation of HDPE fittings within a piping system. Fitting, non-plastic valves, and flange standards would increase the flexibility of piping system design while ensuring reliability of HDPE piping systems.

d) *Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical?*

Does it inhibit the wide application of a specific material or structure class to the nuclear industry?

The gap is related to material data and research concerning the application of elevated temperature and pressure in the nuclear industry. It is critical in the long term, but may be addressed in the short term. The gap for temperature rerating and long-term properties is based on the performance of the resin and manufactured fitting subjected to hydrostatic testing. The rerating values for the fitting geometry are derived from stress analysis based on metallic components. These rerating values lead to conservative design stress values. In order to further validate those values, the impact of multi-axial stress states within fusion joints on SCG resistance and RPM factors are needed to support the development of models with predictive capabilities. In addition, test geometries that reflect the most common stress risers in these fittings should be developed to support SCG resistance and RPM measurements.

5.4 Standards for Joining

5.4.1 Butt Fusion

ASTM F2620 **Standard Practice for Heat Fusion Joining of Polyethylene Piping and Fittings**

a) *Scope and Status today*

Current. Standard was editorially revised in March 2010. This standard is applicable to the nuclear industry since joints are made through the butt fusion process. The standard also addresses saddle and socket fusion practices.

b) *What needs to be changed for application to a nuclear power plant?*

This standard is applicable for conventional HDPE installations. In its current form, the standard is not sufficient and would need changes in detail for the nuclear industry. A new standard would need to be developed specifically for those fusion processes allowed in the nuclear industry.

ASTM F2620 does not adequately address:

(i) A code of practice for large diameter piping that gives the operator guidance on how to:

   a. Measure critical fusion variables and limits to those variables within the field,

b. Determination of whether weather conditions, piping conditions, and fusion equipment fall within the capabilities of a specific operation,
c. How to properly prepare the assembly for fusion,
d. How to properly carry out the fusion,
e. Recordation of the fusion process for record keeping,

(ii) A technical document specific to the large diameter piping fusion instrument and piping manufacturer that defines the critical variables for fusing specific types and sizes of piping:
a. Alignment and diameter tolerances,
b. Cleaning tolerances,
c. Heating/pressure/cooling restrictions,
d. Connection of rheological parameters to fusion processing,

(iii) A methodology for evaluating the combined effects of alignment tolerances, fusion machine, and ambient conditions on the integrity of the joint

(iv) A method to evaluate the integrity of joints, both short and long term performance, in a non-destructive and quantitative manner.

c) *Why does the standard need to be changed?*

Establishing a viable melt bead, controlled movement of the piping during fusion, and controlling the cooling process are critical for developing a successful fusion bond.

a. The standard does not adequately specify where and how often the temperature of the heating tools should be measured and whether those should be recorded. It does not specify the magnitude of a "cold spot".
b. The standard encourages data logging in Appendix X1, but the list is incomplete and not required.
c. The standard does provide specifications regarding minimum heating and cleaning tolerances, but does not address pressure and alignment tolerances. The standard does not address maximum cooling rates, especially where adverse weather conditions may be a concern.
d. The standard does specify in appendix A1 how fusion operations should change based on weather conditions (i.e. hot, cold, wet). Appendix A1 recommends a trial and error procedure to determine appropriate fusing parameters. The standard is not clear whether these conditions can be met for thick walled, large diameter piping.

e. In general, there are large variations allowed for fusion parameters. The impact of these variations on the strength or lifetime of the fusion bond is not immediately clear. For example, temperatures may range between 400 °F to 450 °F and pressures between 60 psi and 90 psi. Similarly, the approximate melt bead size is not consistent between piping sizes. This size can range between 0.039 in (1 mm) to 0.196 in (5 mm) for IPS < 24 in, but there is no variation allowed for IPS > 36 in. These parameters should be better connected to the rheological properties of the piping material. Polyethylene joints were created in large diameter piping by the industry, in conjunction with ASME, using parameters outside the recommended fusion zone. Sections of the joint were removed from the parent joint and tested using tensile, bend back, and impact tests. Preliminary results indicate acceptable fusion joints were generated in large diameter piping fused outside this temperature and pressure window. However, a final report has not been released at this time. This empirical result is positive, but the long-term performance of the fusion joint was not measured in large diameter HDPE piping.

(ii) Overall, this standard relies heavily on visual inspection to identify fusion errors. This type of inspection puts significant trust in the training and experience of the operator. Visual inspection guidelines have been empirically developed and refined, but visual inspections won't identify voids within the fusion zone or regions of minimal diffusion. Secondary testing to validate the fusion procedure and overpressure testing of fused piping sections has been used to qualify procedures.

For example, the ASMEBPV Code Case N-755 specifies a reverse bend test and a high-speed tensile impact test to qualify a fusion procedure. These procedures are not linked to an active ASTM standard. Any procedure used to qualify a fusion operation should be linked to an accepted standard methodology. ASME is developing elevated temperature pressure test guidelines based on ASTM D3035 and the addition of a guided side bend test[9] into the ASME BPV Code Case N-755 for plastic fusing. These tests provide a relative measure of strength over a short time scale without any validation of long-term behavior, sensitivity of test procedure to fusion conditions, and the SCG resistance of the fusion bond. The combined use of multiple tests provides a measure of assurance that

[9] The guided side bend test has been developed by McElroy in conjunction with polyethylene fusion equipment.

the fusion procedure is creating a strong fusion bond, but it is difficult to extrapolate short-term performance to long-term behavior.

d) *Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it inhibit the wide application of a specific material or structure class to the nuclear industry?*

   Due to the success of HDPE piping in the water and natural gas industry, the complexities for successful fusion joining property may be taken for granted when applied to large diameter piping used under elevated temperatures. This gap is critical. The standard would require a rewrite to more narrowly define fusion processing parameters, verification of joint performance, and operator training/qualification. In order to define the essential fusion variables and verify joint performance, an understanding of how fusion parameters influence diffusion and microstructure in bimodal HDPE materials used for large diameter piping is needed. This requires measurements to identify the essential fusion variables to maximize diffusion, develop ideal microstructure within the thermal zone, and minimize void formation and contamination for nuclear HDPE fusions. The impact of microstructural changes on strength and lifetime specific to the fusion joint will also need to be developed to support the essential variables. These concerns have been raised by the U.S. NRC, which will inhibit application to the nuclear industry. This gap is a combination of research and material data for thick walled HDPE piping and the need to identify better test methods, tolerances, and specifications.

   New test methods that are sensitive to relevant failure modes (brittle vs. ductile), stress-state influence on crack initiation and propagation, and failure time-scales of the fusion joint should be identified and developed into standards. An example for fusion joints of piping specimens would be a full piping tensile creep rupture test that increases the axial stress on the fusion joint[10]. These tests should be validated using quality of the fusion joint from both diffusion and microstructure of the HDPE interface. New measurements and material science are required to understand the failure mechanism within the fusion interface as a function of essential variables. Development of methods that quantify joint performance and link performance to microstructural and viscoelastic behavior is important. This will increase the efficiency of the fusion qualification process since a full experimental

[10] Troughton M J and Scandurra A: "Predicting the long-term integrity of butt fusion joints in polyethylene pipings", 17th International Plastic Fuel Gas Piping Symposium, San Francisco, USA, 19-23 October 2002.

characterization will not be required for a new resin, piping diameter, or fitting geometry. Finally, these tests should be used to guide the development and certification of non-destructive evaluation methods that could reliably certify a fusion joint for long-term performance.

Note:

TR-33 Generic Butt Fusion Joining Procedure for Field Joining of Polyethylene Piping

(i) This document describes a generic fusion procedure for fusing HDPE piping very similar to the procedure described in ASTM F2620. The piping materials used to develop this procedure are sufficiently different in geometry and composition than those in consideration for the nuclear industry. Similarly, the tests conducted, according to 49 C.F.R. 192.283, to verify successful fusions do not exactly match those required in ASME Code Case N755. PPI TR-33 being reviewed and expected for publication in 2012.

(ii) There are several ISO standards relevant to fusion joining of HDPE that do address some shortfalls. These are:

a) ISO/DIS 12176-1: Plastics pipings and fittings -- Equipment for fusion jointing polyethylene systems -- Part 1:

b) ISO 12176-2:2008: Plastics pipings and fittings -- Equipment for fusion jointing polyethylene systems -- Part 2: Electrofusion

c) ISO 12176-3:2008: Plastics pipings and fittings -- Equipment for fusion jointing polyethylene systems -- Part 3: Operator's badge

d) ISO 12176-4:2003 Plastics pipings and fittings -- Equipment for fusion jointing polyethylene systems -- Part 4: Traceability coding

e) ISO 21307:2011 Plastics pipings and fittings -- Butt fusion jointing procedures for polyethylene (HDPE) pipings and fittings used in the construction of gas and water distribution systems

5.4.2 Electrofusion

ASTM F1055 – 98 (Reapproved 2006) Standard Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Piping and Tubing

a) Scope and Status today

Major revisions to this standard are currently in the balloting process. Several negatives still need to be resolved.

b) *What needs to be changed for application to a nuclear power plant?*
A separate standard should be developed specifically for nuclear applications, as ASTM F1055 will be very difficult to modify to meet the requirements of the nuclear industry.

ASTM F1055 does not adequately address:

(i) Critical dimensions of fittings and their tolerances,
(ii) Tolerance bands for the resistance of the heating element,
(iii) Tolerance bands for the output of the control box,
(iv) A methodology for evaluating the combined effects of fitting tolerances, control box tolerances and ambient conditions on the integrity of the joint,
(v) The compilation of a technical document in which the fitting manufacturer defines the critical variables for a specific fitting that define the allowed application envelope for fusing:
   a. Maximum allowable gap between piping and fitting,
   b. Maximum allowable ovality of piping to be joined,
   c. Cleaning and contamination controls,
   d. Minimum and maximum allowable ambient temperature at fusion,
   e. Specifications for a suitable power supply for the control box.
(vi) A code of practice that gives the operator guidance on how to:
   a. Measure critical variables in the field,
   b. How to determine if a particular piping/fitting/ambient conditions combination fall within the capabilities of the specific fitting,
   c. How to properly prepare the assembly for fusion, and
   d. How to properly carry out the fusion.

c) *Why does the standard need to be changed?*

The current standard is widely accepted as a sufficiently well defined and appropriate standard for conventional HDPE installations. The nuclear plant will require significantly more information about the fusion process for accident investigation and maintenance records. The development of a technical document and code of practice will form the basis to gather that information. Identifying tolerances for equipment and piping dimensions will facilitate better quality control of fusion joints across operators and climate zones.

Qualification tests provide a relative measure of strength over a short time scale without any validation of long-term behavior or an quantification of test sensitivity. New test methods that are sensitive to the relevant failure modes (ductile and brittle) and time-scales within the fusion joint should be developed and incorporated into the standard. These tests should be validated against quality of the fusion joint from both diffusion and microstructure of the HDPE interface. Finally, those tests should be used to guide the development and certification of non-destructive evaluation methods that could reliably certify a fusion joint for long-term performance.

d) *Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it inhibit the wide application of a specific material or structure class to the nuclear industry?*

It is essential to address these gaps before electrofusion can be fully supported in Essential Service Water and other safety related applications in the nuclear industry. This gap is critical. The standard would require a rewrite to more narrowly define fusion processing parameters, verification of joint performance, and operator training/qualification. In addition, references for the limits of fusion processing variables for current nuclear HDPE should be provided. The U.S. NRC that will inhibit application to the nuclear industry has raised these concerns. This gap is a combination of research and material data for thick walled HDPE piping and the need to identify better test methods, tolerances, and specifications.

Note:

(i) PPI document TN34 addresses some of the code of practice issues for large diameter electrofusion fittings. The lack of a standard that defines the items listed in c) above makes it difficult to properly quantify the allowable limits in a field application.

(ii) ISO 8085-3 Polyethylene fittings for use with polyethylene pipings for the supply of gaseous fuels -- Metric series -- Specifications -- Part 3: Electrofusion fittings. ISO 8085-3 has some of the definitions listed above, but incorporates several other ISO standards that are not recognized in the U.S. ISO 8085-3 also needs to be more tightly defined in some areas to be suitable for nuclear applications.

5.5 Long-term Performance Standards

A challenge for long time performance in HDPE piping perceived by the PPTG is the lack of quantitative tests for lifetime prediction. The standard test methods available for generating long time data and analyzing this data are not quantitative service life predictors. Some test methods, such as PENT, serve only as index tests to rank one HDPE compound against another in terms of performance and have not been tied directly to service life. The standards are used to identify failure conditions and failure type under accelerated conditions in order to specify a hydrostatic design basis (HDB), hydrostatic design stress (HDS), and resistance to slow crack growth. These standards have been used effectively in the water and gas industry for decades to safely design piping systems, but they remain a guide for selecting a resin for long-term performance rather than a quantitative lifetime prediction.

The ASME and U.S. NRC approach to design of a piping system, especially the long-time performance, is broken into three areas: standards for piping compounds, standards for piping, and standards for fusions and fittings. There is overlap of standards within the piping and fitting areas where one standard is used in both instances. There are four important questions that need to be answered within the piping, fusion, and fitting areas: How high a pressure and at what temperature can the piping withstand for a design lifetime under specific operation conditions? Will the piping fail in a ductile or brittle manner during the design lifetime? What is the impact of a stress riser (i.e. stress concentration) (e.g. void, chemical degradation, gouge, edge) on that design lifetime expectation which is not already considered by the current test methods? What is the resistance of the piping, fusion, or fitting to rapid crack propagation? This section will be arranged to address standards that are specific to collecting and analyzing the long time data for materials (polyethylene) and objects (piping or fusion).

5.5.1 Standards for PE Compounds

ASTM D1693 **Standard Test Method for Environmental Stress-Cracking of Ethylene Plastics**

a) *Scope and Status today*
   Current addition approved March 1, 2008 and published March 2008. Originally approved in 1959.

b) *What needs to be changed for application to a nuclear power plant?*
   This test method covers the determination of the susceptibility of ethylene plastics to environmental stress cracking when subjected to the presence of accelerating liquids. This standard is not suitable for application to nuclear power

plant. There are many variables and the test does not produce time to failure that is related to the applied stress or temperature, which is important for the nuclear industry. ASTM D1693 is not a regularly used test method for HDPE pressure piping used today.

c) *Why does the standard need to be changed?*
The significant variables, according to the standard, are stress at the point of crack initiation, specimen thickness, and notch depth. These can be hard to control from laboratory to laboratory and when controlled the standard deviation remains above 10%. Since HDPE compounds stress relax over time under conditions of constant strain, the stress will dissipate over time and become negligible.

d) Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it inhibit the wide application of a specific material or structure class to the nuclear industry?
This gap is related to the adoption of an accelerated notch failure test that utilized a stress cracking liquid. ISO standard 16770: 2004 Plastics. Determination of environmental stress cracking (ESC) of polyethylene (HDPE). Full-notch creep test (FNCT) utilizes a full notch specimen under constant load and immersed in an accelerating liquid. The stress and specimen dimensions are sufficiently satisfied to satisfy the gaps identified in ASTM D1693. In addition, the application of a constant stress condition in ISO 16770 prevents relaxation of the polyethylene to reduce the imposed stress compared to the constant strain imposed in the ASTM standard.

ASTM D1473 **Standard Test Method for Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipings and Resins**

a) Scope and Status today
Current addition approved May 1, 2007 and published May 2007. Originally approved in 1997.

b) *What needs to be changed for application to a nuclear power plant?*
This test method determines the relative resistance of polyethylene materials to slow crack growth under conditions specified in the standard (2.4 MPa and 80 °C). It is currently used in ASTM 3350 and ASME Code Case N-755. Certain changes should be addressed to improve testing of large diameter piping for nuclear applications:

(i) Samples are constructed from piping or compression molded plaques. Thermal and stress history can impact slow crack growth resistance of

HDPE materials[11,12]. The impact of these processing methods on failure times is not adequately documented in the standard.

(ii) When samples are cut from piping with a wall thicker than 0.79 in (20 mm), the sample must be machined to the proper thickness. The side opposite to the machined surface is notched. The standard does not provide guidance on how to handle piping specimens where a cooling gradient from extrusion may result in a gradient in material properties.

(iii) The standard does not provide equations to calculate the stress intensity factor of the notch or the stress intensity factor as a function of the growing notch.

(iv) The standard does not provide guidance on identifying tests that may result in extended failure times due to ductile failure in the last ligament of the specimen at end of test.

(v) The standard notch dimensions provides for a constant stress intensity factor, but the standard does not address slow crack growth resistance of failures created by flaws different than the standard notch dimensions that is a concern for the U.S. NRC.

(vi) The standard does not identify how failure times from ASTM D1473 relate to the elevated temperature, long time performance measured in ASTM D2837. ASTM D1473 is expected to provide a conservative estimate of long time performance, assuming the stress intensity at the notch tip is much larger than any flaw induced into the piping within the field.

c) *Why does the standard need to be changed?*
This standard forms the backbone for the measurement of the slow crack growth resistance of HDPE material used in piping. Given the larger diameters used by the nuclear industry and specific questions from the U.S. NRC, the standard would need to be better specified to properly address those concerns.

d) Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it inhibit the wide application of a specific material or structure class to the nuclear industry?
Currently, ASME Code Case N-755 specifies no flaw within the piping to maintain the conservative estimate provided by ASTM D1473. This gap is related to the specific application of large diameter piping in the nuclear plant and would become

[11] Lu, X; Brown, N; "Effect of thermal history on the initiation of slow crack growth in linear polyethylene" *Polymer*, 28 (1987) 1505-1511.
[12] Shah, A; Stepanov, EV; Klein, M; Hiltner, A; Baer, E; "Study of polyethylene piping resins by a fatigue test that simulates crack propagation in a real piping" *Journal of Material Science* 33 (1998) 3313-3319.

critical for the adoption of this slow crack growth resistance test to evaluate SCG resistance of flaws in piping.

***ASTM D3350* Standard Specification for Polyethylene Plastics Piping and Fittings Materials**

a) *Scope and Status today*
Current addition approved Jan. 1, 2010 and published February 2010. Originally approved in 1974. This standard outlays standard specifications for identification of polyethyelene plastic piping and fittings in conjunction with the cell classification system. It is not specific to developing data or design procedures for lifetime prediction. It would not need to be changed unless referenced ASTM standards (D1693, D1473, D2837) are changed to new standards for nuclear industry applications.

b) *What needs to be changed for application to a nuclear power plant?*
Not Applicable

c) *Why does the standard need to be changed?*
Not Applicable

d) *Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it inhibit the wide application of a specific material or structure class to the nuclear industry?*
Not Applicable

5.5.2 Standards for HDPE Piping

***ASTM D3035* Standard Specification for Polyethylene (PE) Plastic Piping (DR-PR) Based on Controlled Outside Diameter**

a) *Scope and Status today*
Current addition approved March 1, 2008 and published March 2008[13]. Originally approved in 1972. This standard describes standard specifications for polyethylene made in dimension ratios based on outside diameter and pressure rated for water.

[13] ASTM D3035 has been updated to ASTM D3035-12e1 in 2012. This updated standard was not issued for PPTG review at the time of publication.

b) *What needs to be changed for application to a nuclear power plant?*
The standard specifies ASTM D1598 for long term hydrostatic testing, but does not specify a verification of slow crack growth resistance of produced piping beyond the elevated hydrostatic test requirements of the standard.

c) *Why does the standard need to be changed?*
Slow crack growth resistance is a criterion for HDPE piping in the nuclear industry and should be verified in addition to long term hydrostatic testing. Currently, slow crack growth is treated as a material property and addressed within ASTM D3350. The rational is the PENT test provides the aggressive environment for SCG, therefore the piping performance would be higher than in the PENT test. An example of a slow crack growth resistance standard measurement for piping is ISO 13479-1997 which specifies inducing an axial notch of specific dimensions in a piping sample and measuring failure time. Since this is a specification of the code case and all references to other testing required by the ASME Code Case N-755 should be located in one standard to limit the potential confusion.

d) Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it inhibit the wide application of a specific material or structure class to the nuclear industry?
The gap is not necessarily critical because the ASME Code Case N-755 and ASTM D3350 reference notch testing for (PENT) slow crack growth resistance. Reducing the number of specified standards to only those needed for qualification, ordering, and specifying materials can reduce confusion and improve efficiency.

***ASTM F714* Standard Specification for Polyethylene (PE) Plastic Piping (SDR-PR) Based on Outside Diameter**

a) Scope and Status today
Current addition approved Dec 1, 2010 and published January 2011[14]. Originally approved in 1981. This standard describes standard specifications for polyethylene made in dimension ratios based on outside diameter greater than 3.5 in and suitable for transport of water, municipal sewage, domestic sewage, industrial process liquids, effluents, and slurries, etc.

[14] ASTM F714 has been updated to ASTM F714-12a in 2012. This updated standard was not issued for PPTG review at the time of publication.

b) *What needs to be changed for application to a nuclear power plant?*
The standard specifies ASTM D1598 for long term hydrostatic testing, but does not specify a verification of slow crack growth resistance of produced piping beyond the elevated hydrostatic test requirements of the standard.

c) *Why does the standard need to be changed?*
Slow crack growth resistance is a criterion for HDPE piping in the nuclear industry and should be verified in addition to long term hydrostatic testing.

d) Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it inhibit the wide application of a specific material or structure class to the nuclear industry?
The gap is not necessarily critical because the ASTM Code Case N-755 and ASTM D3350 reference notch testing for slow crack growth resistance. Reducing the number of specified standards to only those needed for qualification, ordering, and specifying materials can reduce confusion and improve efficiency.

ASTM 1598-02 **Standard Test Method for Time-to-Failure of Plastic Piping Under Constant Internal Pressure**

a) Scope and Status today
Current addition approved Aug 1, 2009 and published January 2009. Originally approved in 1958. This standard describes the method to test the failure of plastic piping subjected to internal hydrostatic pressure.

b) *What needs to be changed for application to a nuclear power plant?*
The internal pressure of the piping is measured and the piping may be exposed in a water bath or gaseous environment to maintain a constant temperature. The procedure provides recommendation for identifying failures and rejecting biased failures. Hoop stress calculations are also provided to convert pressure to stress on piping. The test fluid chemistry and stability is not sufficiently specified and flow is not specified.

c) *Why does the standard need to be changed?*
The test fluid chemistry is not sufficiently specified and flow through the piping is not specified. The test fluid plays a critical role in the accelerated aging of the piping interior by potentially removing anti-oxidants and inducing oxidative attack. In addition, static fluid may exhibit water chemistry changes over the

lifetime of the test[15]. Conversely, a flowing system using recirculation of fresh test fluid continues to promote hydrolysis and diffusion of anti-oxidants that could affect testing in a flowing environment.. These variations could affect the long-term piping test and should be sufficiently specified and controlled.

d) *Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it inhibit the wide application of a specific material or structure class to the nuclear industry?*
This gap is critical and is the result of a need for more research on polyethylene. There have been a number of studies conducted in the literature to identify the impact of chemical oxidative attack on piping performance, but these results are not reflected within the standard. Materials research is required to understand the unique role of nuclear service water chemistry on the health and performance of HDPE piping for nuclear applications. These conditions should be reflected within the standards developed for hydrostatic testing.

ISO 13479 **Polyolefin pipings for the conveyance of fluids – Determination of resistance to crack propagation – Test method for slow crack growth on notched pipings.**

a) *Scope and Status today*
Second edition 9-15-2009. This test method covers the determination of the resistance to crack propagation of polyolefin piping determined by the time to failure of a hydrostatic pressure test. The piping has a machined longitudinal notch on the outside surface and is applicable to wall thickness greater than 5 mm. The machine adequately specifies how to prepare specimens and conduct tests. Test standard is missing tolerances on test temperature and pressure conditions.

b) *What needs to be changed for application to a nuclear power plant?*
The applicability of ISO 13479 for the large diameters (> 36" in) used in nuclear water piping should be investigated in order to determine whether hydrostatic testing of notched piping will provide a quantitative measure of SCG resistance in piping or whether alternative methods should be developed for piping testing.

[15] Whelton, AJ; Dietrich, AM; Gallagher, DL; "Impact of chlorinated water exposure on contaminant transport and surface and bulk properties of high-density polyethylene and cross-linked polyethylene potable water pipings" *Journal of Environmental Engineering* 137 (2011) 559.

c) *Why does the standard need to be changed?*
   Not applicable – possibly change to incorporate competing effects such as alignment or chemical degradation and the incorporation of notch geometries that would represent flaws induced by damage during installation.

d) *Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it inhibit the wide application of a specific material or structure class to the nuclear industry?*
   Not applicable.

5.5.3 Standards for HDPE Fusions

There is no specific standard to address HDPE fusion performance over the long term. ASTM D3035 has been used develop a long term performance measure of fusions, but this test does not stress the fusion region due to the concentration of hydrostatic stress in the hoop stress of the piping. There have been attempts to apply notch testing such as ASTM F1473 to fusion bonds, but this is difficult to drive crack propagation at the interface. In addition, this test does not represent the typical stress state within a fused piping specimen. A test method and standard should be adopted for quantifying fusion performance over long time. This test should provide a measure of SCG resistance of the joint within a realistic stress state of the in-service fusion joint. In addition, the test method should provide a measure of the true strength of the joint to facilitate appropriate HDS rating of the fusion.

ASTM F2018 "Standard Test Method for Time-to-Failure of Plastics using Plane-Strain Tensile specimens" is a potential coupon test method that has been shown to induce a biaxial stress state within the plastic specimen. Another test method is a full piping creep rupture test that permits long time testing of a fusion joint at temperature and pressure. This test focuses stress in the axial direction to induce failure within the joint and not the parent piping[10], but a standard could not be identified for this test method.

5.5.4 Standards to Evaluate Surface Flaws in HDPE piping

There are currently no standards specifically developed to address the impact of surface flaws on the lifetime and performance of piping. This is a critical gap because ASME has removed any flaw tolerance acceptance for HDPE piping.

5.5.5 Standards for NDE Testing of Volumetric Flaws

Volumetric flaws can occur within the wall of a piping or fitting during the manufacturing process. The location and geometry of the flaw in conjunction with the surrounding environment will determine whether the flaw will grow over time, but there is no clear understanding of the statistical distribution of flaw locations and geometries induced during the manufacture and installation of large diameter HDPE piping. Industry partners (Duke Energy, Structural Integrity, TWI, and EPRI) have been investigating, in parallel, various commercial methods to identify feasibility for use in the investigation of large diameter polyethylene piping fusions. The Pacific Northwest Laboratory has been working with ASME to identify the critical parameters to improve NDE sensitivity to flaws within the fusion joint and piping. It is recommended to identify the risk of failure for a piping system over time as a function of flaw geometry, location, and operating environment. This understanding may be used to guide the development of reliable volumetric test methods with sensitivity and resolution tailored to the needs of the nuclear industry.

5.5.6 Standards to Develop HDB/HDS at Long-times

There are two methods to develop the strength of piping over long times, ASTM D2837 and ISO 9080. These tests are not service life or even design life predictors. The test provides a methodology to identify the failure modes of HDPE piping at long times based on the visco-elastic creep behavior of HDPE. The Arrhenius behavior of the ductile and brittle failure modes may also be examined with these methods. External factors such as chemical exposure, damage or pressure cycles, and fusion joints affect these curves, which will not be measured using the current test methodologies.

There is one reference that specifically addresses the differences[16] between ASTM and ISO methods and another which describes the design reference strength (DRS) analysis to harmonize the two methods[17]. Specific key differences will be addressed in this section, but readers are encouraged to view Boros[16] and Zhou et al.[17] Both standard methods have been used to predict the strength of piping. The two methodologies are similar, but there are differences that must be considered when using the results from either method. The ISO method utilizes multiple temperatures tests to generate both the ductile and brittle failure envelopes for a piping material, where practical. The ASTM method calculates the HDB at 100,000 hours (11.4 yrs) and requires validation of linearity of ductile failure at ambient and elevated temperatures. ASTM D2837 uses the mean failure stress to specify the HDB. The ISO method extrapolates to a 50 yr basis to determine the LTHS of the piping material, which is then categorized into a Minimum Required Strength (MRS).
The MRS is based on the 97.5% lower predictive limit at the 50 yr extrapolation. The ISO method permits designation of HDS using the brittle failure envelope, where ASTM only allows long-term forecast of strength based on ductile failure. Both methods utilize different design factors to arrive at an appropriate HDS, but the calculation of HDS is

[16] Boros, SJ; "ASTM vs ISO Methodology for Pressure Design of Polyethylene Piping Materials" PPI XX
[17] Zhou, ZJ; Palermo, EJ; " Can ISO MRS and ASTM HDB Rated Materials Be Harmonized?" Plastics Piping XII, Milan, Italy (2004)

slightly different. Ultimately, the differences between the HDS for piping design stress are subtle despite the differences in methodology.

A current challenge for ASME is identifying the design life of HDPE piping put into service today for regulators and the reasonable expected lifetime of that piping material. The current ASTM standard provides a reliable method for understanding the Arrhenius behavior of the ductile failure of HDPE piping, but brittle failure is the mode associated with SCG. This mode is captured within coupon level PENT testing of resins through ASTM D1473.

***ASTM D2837* Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Piping Materials or Pressure Design Basis for Thermoplastic Piping Products**

a) *Scope and Status today*
Second edition 9-15-2009. This standard describes the method to develop the limit of strength of a piping subjected to long hydrostatic pressure for long times. This standard provides a methodology to develop a design basis for thermoplastic piping using hydrostatic testing at elevated temperatures. This method has been used for many years to successfully quantify the long-term strength of polyethylene piping. The standard provides a test of long-term performance, but is not a lifetime prediction tool.

b) *What needs to be changed for application to a nuclear power plant?*
Currently, there is no substantiation requirement for HDB at 140 °F (60 °C), a common maximum design temperature of nuclear piping..

c) *Why does the standard need to be changed?*
Substantiation is additional testing at elevated temperature, usually 80 °C (176 °F) or 90 °C (193 °F), to demonstrate linearity of the stress regression out to a 50 yrs. PPI TR-3 provides a methodology to substantiate performance to 23 °C (73 °F). There is no methodology to substantiate performance at 60 °C (140 °F)

d) *Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it inhibit the wide application of a specific material or structure class to the nuclear industry?*
The gap is important for predicting the long-term performance of HDPE piping materials. The methodology exists for developing these measurements, thus incorporating changes for the nuclear industry could satisfy the gap. Further

investigation into the merits of imposing this additional requirement should be made.

ISO 9080 **Plastics piping and ducting systems – Determination of the long-term hydrostatic strength of thermoplastics materials in piping form by extrapolation – this should be a general discussion of this standard.**

a) *Scope and Status today*
   First edition was 1-15-2003. Prior to this time it was published and utilized as a Technical Report, TR, within ISO. This standard describes the method to develop the limit of strength of a piping subjected to long hydrostatic pressure for long times. The test allows for the identification of the ductile and brittle failure regions and provides for a long-term strength forecast based on either failure mechanism.

b) *What needs to be changed for application to a nuclear power plant?*
   This standard would need to be updated to account for the elevated temperature use of HDPE in a nuclear application and the validation of a single lot of material from a specific resin producer.

c) *Why does the standard need to be changed?*
   The development of rate process method factors should reflect the intended use of nuclear HDPE piping at higher temperature rather than the lower temperature of water and gas piping.

d) *Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it inhibit the wide application of a specific material or structure class to the nuclear industry?*
   The gap is related to the specific use of piping application conditions within a nuclear plant and should be reflected within the standard.

5.6 Standards for Chemical Resistance

ASTM F2263: Standard Test Method for Evaluating the Oxidative Resistance of PE Piping to Chlorinated Water

a) *Status today*
   Current. This standard describes a test method to evaluate the oxidative resistance of HDPE piping to chlorinated water.

b) *What needs to be changed for application to a nuclear power plant?*

This standard does not offer specifics on chlorine level, water quality, test temperature, and duration. These values are left up to the test administrator.

c) *Why does the standard need to be changed?*
The test conditions for determining the oxidative resistance of HDPE piping to chlorinated water should be specified relevant to use conditions (concentration and temperature) experienced in a service water applications. This includes the chemicals used in nuclear plant service water (e.g. chemical type, continuous, or intermittent use), the source of nuclear plant service water such as lakes or salt water, piping stress, piping wall thickness, type of application (e.g., continuous or intermittent flow).

d) *Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it inhibit the wide application of a specific material or structure class to the nuclear industry?*
This is a critical gap related to a lack of specifications for the application of HDPE to service water applications. Research and material data are needed relevant to the conditions and chemicals in use by the nuclear industry[18].

PPI TR-19/2007: Chemical Resistance of Thermoplastics Piping Materials

a) *Status today*
Current. This technical report recommends which chemicals to use/not use with polyethylene. It does not provide a test protocol to test chemicals against polyethylene and is only a short-term exposure test that uses either weight gain or loss as an indicator of resistance to a certain chemical.

b) *What needs to be changed for application to a nuclear power plant?*
It does not distinguish the difference between various types of polyethylene, for example LDPE and HDPE.

c) *Why does the standard need to be changed?*
If this technical report were to be transitioned to a standard, than it would require more quantitative information on testing procedures and evaluation procedures for the different polyethylene materials, chemical exposure levels, and exposure times.

d) *Is the gap related to a lack of research, material data, or a specific application of the nuclear industry such as pressure or temperature? Is the gap critical? Does it*

[18] There is a current project at EPRI investigating the effect of oxidants on piping life at plant operating conditions; "2012-05 HDPE Piping Aging Degradation Mechanisms".

inhibit the wide application of a specific material or structure class to the nuclear industry?

This gap is related to a lack of research available to define standards for chemical resistance for the bimodal polyethylene materials considered in use for the nuclear industry in service water applications. Certain chemicals used at nuclear power plants are not listed in this chemical resistance table. The impact of chemical exposure (short/long term) on long-term performance is not described.

6 Gaps in Current Standards

A review of current HPDE or piping related standards for specific applications were identified in Section 5. This section provides a compilation of those recommendations and potential time frame to fill standardization gaps. The final sections of the table contain a list of areas where gaps exist, but no specific standard has been reviewed by the PPTG. These standards have been compiled under the heading of **Other Standards Gaps**. The roadmap, presented in Section 7, will provide input on the mechanisms available to fulfill these gaps. The far column lists any solution provided by ASME Code Case N-755. This provides a reference of where the current intent is to increase either specification or test methodology within the code rather than develop a new standard. In some cases, it may not be feasible to create or modify a standard with nuclear performance requirements that are not needed within the water or gas industry. In other cases, amendments may be made to the standard to highlight nuclear requirements and provide a level of efficiency to standards documentation. The gap analysis is intended to serve as a starting point for future discussion within NESCC, ASME, ASTM, and the U.S. NRC on advancing current standards for the nuclear power plants using polyethylene piping. The gaps are compiled into Table 1.

Table 1: Standards gaps identified by the PPTG in regard to the application of polyethylene piping to the nuclear industry

Report Section	Page	Standard	Recommendations	Time Frame*	Code Case N-755-1	Priority	NRC Ranking
5.1 Standards for Pipe Resins	**13**	ASTM D3350	A new or amended standard that addresses resin properties that are critical to nuclear industry.	ST	Appendix III Table IV-121, IV-141.1, IV-141.2, IV-141.3, and IV-142.1 set minimum quality test requirements	Normal	1
			Change induction time measurement to OIT measurement for thermal stability of resin	ST		Normal	2
5.2 Standards for Design Basis and Strength	**15**	ASTM D2837 & TR-3	A distinct accounting for the design factor (DF).	ST	Requires classification of PE 4710 in PPI TR-4	Routine	3
			Substantiation of the linearity of HDB curve at 140 ^{o}F, not just at 23 ^{o}F.	ST	Table-3131-1(a) and -3210-3(a), provide allowable stress and modulus of elasticity with temperature	Normal	1
			Testing applications for a 60 year life at elevated temperature$^{\$}$	MT		Normal	1
			A method to account for creep behavior during excusions above 140 ^{o}F	MT		@	1
5.3 Standards for Valves and Fittings	**17**	ASTM F2880	Expansion of standards to different types of fittings with the inclusion of validated temperature and pressure derating tables	MT	Section -22210 and -2220 address mitered elbows and flange adaptors	Normal	2
5.4 Standards for Joining *Butt Fusion*	*19*	ASTM F2620 & PPI TR-33	A minimum code of practice for operators	ST	References ISO 19480/2005	Normal	1
			A technical document specific to fusion machines and pipe manufacturers that defines essential variables for fusing pipe.	ST	Mandatory Appendix I addresses minimum training and fusion procedure qualifications	@	1
		ASTM F2880 & PPI TR-33	Data acquisition forms for record keeping	ST	I-220 provides fusion procedure specification; Appendix C provides pictures	Normal	1
			A methodology for evaluating the combined effects of alignment tolerances, fusion machine, and ambient conditions on the integrity of the joint	MT	Mandatory Appendix II data report forms	Normal	1
			A technical document that identifies destructive and non-destructive testing that reflect short and long term viability of fusion joint	LT	Appendix I: Section I-130 and I-302 specifies minimum testing required for fusion procedure qualification	Normal	1
Electrofusion	*24*	ASTM F1055 & PPI TN-34	A minimum code of practice for operators	ST		Normal	2

Table 2: Standards gaps identified by the PPTG in regard to the application of polyethylene piping to the nuclear industry

Report Section	Page	Standard	Recommendations	Time Frame*	Code Case N-755-1	Priority	NRC Ranking
5.4 Standards for Joining, cont.	*24*		A technical document specific to electrofusion instruments and pipe manufacturers that defines essential variables for fusing pipe.	ST		Normal	2
Electrofusion, cont'd.			Data acquisition forms for record keeping	ST		Normal	2
			A methodology for evaluating the combined effects of fitting tolerances, control box tolerances and ambient conditions on the integrity of the joint,	MT		Normal	2
			A technical document that identifies destructive and non-destructive testing that reflect short and long term viability of fusion joint	MT		Normal	2
Long-Term Performance							
5.5.1 Standards for PE Compounds	**26**	ASTM D1693	Difficult to control essential variables for this test; such as stress at point of crack initiation, specimen thickness and notch depth.	LT		Normal	2
			Failure in this geometry does not predict the accurate time to failure of pipe	LT		Normal	2
		ASTM F1473	Impact of processing samples (pipe vs. compression molded) on failure times not adequately documented	ST		Routine	2
			Methods to section thick pipe do not account for potential gradients in microstructure or residual stress	ST	I-131.3(c) recommends cutting pipe with wall thickness greater than 2.5 mm in two.	Routine	2
			No equations to calculate stress intensity factor changes with notch growth	ST		@	2
		ASTM F1473	No method to address ductile failure at end of PENT test	ST	Table IV-142(a): PENT time extended to 2000 hrs. at 2.4 MPa and 80 °C.	Normal	2
			These methods do not nescessarily support long time models for prediction	LT		Normal	2
		Overall	There is no quantitative link between long time performance and actual service life prediction	LT		@	2
			Does not provide specific instructions for testing fusion specimens	MT	Mandatory Appendix I addresses minimum training and fusion procedure qualifications	@	2
5.5.2 Standards for PE Pipe	**29**	ASTM D3035	Does not specify F1473, but specifies D1598 for pipe testing	ST		Normal	2
		ASTM F714	Does not specify F1473, but specifies D1598 for pipe testing	ST		Normal	2
		ASTM D1598	Test fluid and flow through pipe not specified	ST		Normal	2

Table 3: Standards gaps identified by the PPTG in regard to the application of polyethylene piping to the nuclear industry

Report Section	Page	Standard	Recommendations	Time Frame*	Code Case N-755-1	Priority	NRC Ranking
5.5.3 Standards for PE Fusions	**32**		No specific standards developed for testing long-term behavior of PE fusions	MT		Normal	1
5.5.4 Standards to Evaluate Surface Flaws	**33**		No standards to address characterization of surface flaws and the impact on long-term behavior	MT		Normal	1
							1
5.5.5 Standards for Non-Destructive Examination	**33**		Test methods and equipment are available to conduct a volumetric inspection of a pipe and fusion. There is no specific criteria that links critical flaw geometry or lack of fusion to the risk of failure.	MT		Normal	1
5.5.6 Standards to Develop HDB/HDS at Long-Times	**33**	D2837, ISO 9080	Substantiation of the linearity of HDB curve at 140 ^{o}F, not just at 23 ^{o}F.	ST		Normal	1
		Overall	There is no quantitative link between long time performance and actual service life prediction	LT		Normal	2
5.6 Standards for Chemical Resistance	**36**	ASTM F2263	Test conditions for oxidative resistance of PE pipe to chlorinated water should specified relevant to use conditions in service water.	ST		Normal	1
		PPI TR-19	Test protocol needed for testing chemicals against polyethylene, that accounts for PE molecular weight.	ST		Normal	2
			Identification of experimental controls such as chemical exposure levels, times and a more thorough identification of degradation via OIT or Spectroscopy.	LT		Normal	2
		Overall	Develop a derating standard based on the type and level of chemical exposure of a pipe material in a nuclear plant.	LT		Normal	2
Ancillary Standard Gaps							
Pipe Hangers and Supports	37	ANSI/MSS SP-58-2009	Hangers and supports have a critical role with regard to piping and standards should be addressed as piping transitions from buried into the plant	ST		Normal	2
Seismic Design	38	ASME B31E-2008	Standards should be specified for seismic design	ST	Design equations provided in Appendix D Nonmandatory Seismic Analysis Method	@	2
Fire Resistance	38		The resistance to fire and specific measures required to reduce fire risk should be determined for pipe materials where a risk of fire is present.	ST		Normal	2

Table 4: Standards gaps identified by the PPTG in regard to the application of polyethylene piping to the nuclear industry

Report Section	Page	Standard	Recommendations	Time Frame*	Code Case N-755-1	Priority	NRC Ranking
UV resistance			Standards to evaluate and rank the resistance to UV are not addressed for pipe transitions that may occur above ground and exposed to sunlight.	MT		Normal	2

*Time Frame: short term (ST): < 3 years; medium term (MT): 3-8 years; long term (LT): > 8 years

[$] Nuclear power plants are currently certified for operation for 40 years with an opportunity to extend operation 20 years.

@ There was no clear high rank for a priority

Priority Listing

Routine: a *routine* enabling technology or safety issue that requires *no special* SDO support.
The gap may be addressed during the next periodic review.

Normal: an *imprtant* enabling technology or safety issue that requires *enhanced* SDO support.
This gap would require a coordinated approach to resolve.

Expedited: a *key* enabling technology or safety issue that requires *focused* SDO and *Stakeholde* r support.
This gap requires expedited SDO and Regulatory action.

NRC Ranking

1. Issue requires resolution for NRC acceptance of N-755.
2. Issue needs addressed, but not for NRC acceptance of N-755.
(e.g. required for future anticipated applications)
3. Issue is considered resolved for NRC purposes.

7 Roadmap for the Next Decade

In the previous section, gaps in the standards that pertain to the nuclear industry were identified. Identifying these gaps is an important first step to developing the standards needed to facilitate the incorporation of materials and composites for water transport in nuclear plants. It is critical that a consensus path is developed to address those standards gaps such that SDO's, regulators, manufacturers, and operators can take action and close these gaps. The roadmap was developed by the PPTG through evaluation of the standards gaps for nuclear piping. The breakdown of topics follows the format of Section 5 and the time frame to fill the gap has been broken down as:

- Short Term – less than 3 years
- Medium Term – 3 years to 8 years
- Long Term – longer than 8 years

These have been developed from discussion with the ASME working group on HDPE research and the NESCC task group recommendations.

7.1 Standards and Technology Roadmap

Figure 1 provides an overview of the connectivity between standards that might be employed for HDPE piping for nuclear water applications. The top of the figure represents standards related to the polyethylene resin and the bottom represents standards related to the management of the HDPE piping system. The standards listed on the left represent those that pertain to the particular area such as resin, piping, joint, or system. The boxes within the center of the diagram represent areas where standards do not currently address gaps in HDPE for large diameter piping for buried water service. At the smallest length scale, measurements, metrologies and models are developed to quantify structure-property relationships for high performance resins. These quantify the impact of resin architecture, formulation, and thermal processing on the critical properties of the bimodal resin prior to manufacturing into a piping. At the next level down the resin has been processed into a piping and potentially assembled into the distribution system via joints, valves, and fittings. At this level, new standards are required to quantify the fracture mechanics that govern failure within critical components such as flawed piping, joints, fittings or valves. These fracture geometries may include specialized test coupons, full piping testing, and fusions with or without notches. Each standard should provide a measure of the limits of performance for large diameter piping and not specific to manufacturer or manufacturing process. Examples of the output from the test would be strength, creep, slow crack growth and rapid crack propagation quantities that provide designers and manufacturers the tools to specify the piping to meet a performance requirement. These fracture geometries developed for pristine piping provide the means to conduct lifetime analysis within accelerated environments that represent plant conditions over the course of 40 to 60 years.

Therefore, the standards developed within the lifetime prediction (third level) build upon the other levels to quantify the performance of the piping in service over extended periods. This includes previous creep and slow crack growth standards or additional stresses such as transient pressure and temperature, degradation of service from environmental stresses, risk of failure from flaws, and fitting connections. The standards from each level should facilitate the development of integrity management methods and models, where the quantitative performance (design parameters) and material data (constitutive models) developed prior are utilized to understand the probability of failure under a multitude of scenarios. The ability to structure standards in such a manner should allow the development of tools that are specific to the three critical stakeholders for nuclear power plant water service. These are the manufacturers and designers that are developing the next generation of materials, the utilities that must manage the systems once they are in place for over 60 years, and the regulators whom are trusted to safeguard the operation of these systems through their lifetime.

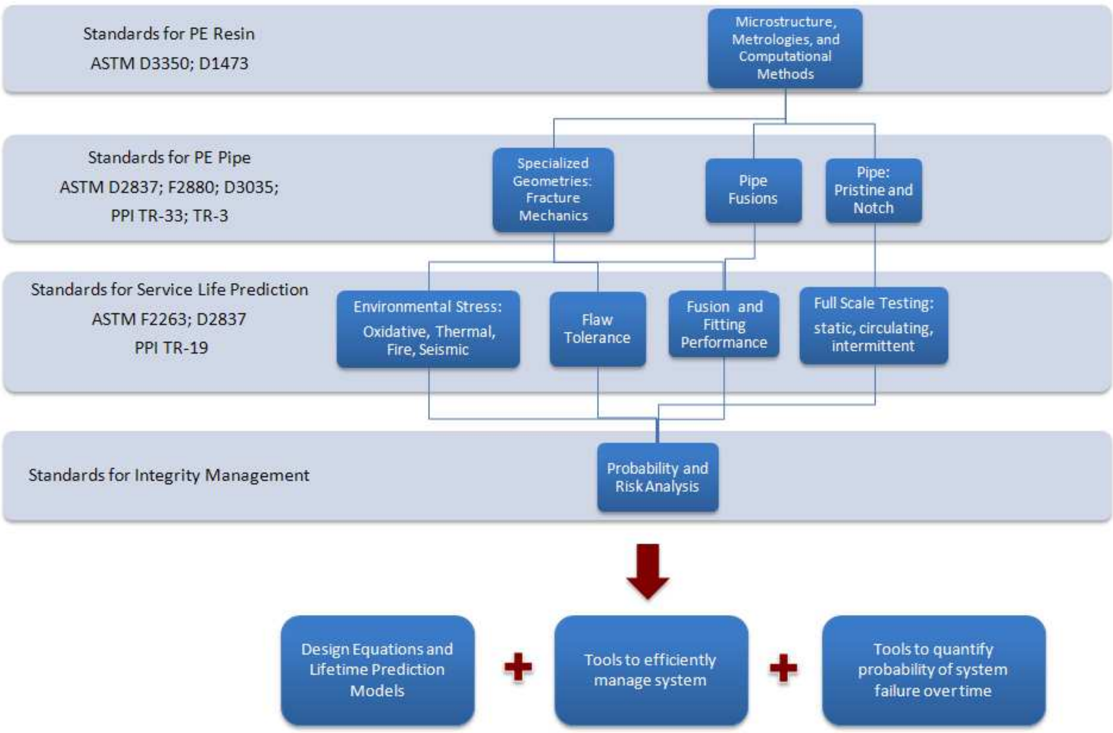

Figure 1: Overall roadmap for the development of standards to support HDPE nuclear service water and provide tools for piping manufacturers, utilities, and regulators.

It is possible to further break-down the gaps identified within Section 5 and organized in Section 6 of the report into general timelines. In the following section, the gap table has been used to identify specific tasks and their interconnectivity for completing tasks. The figures are read from left to right, where the red dotted boxes indicate a 3 year time frame, the solid blue boxes are a 3 to 8 year timeframe, and the green dash-dot boxes indicate a time frame greater than 8 years. These timelines were estimates developed through the discussions within the PPTG and are not representative of current research or standards programs. The final section in this chapter details specifically who may be responsible for completing these tasks.

….. Short term 0-3 years
___ Medium Term 3 – 8 years
._._. Long Term > 8 years

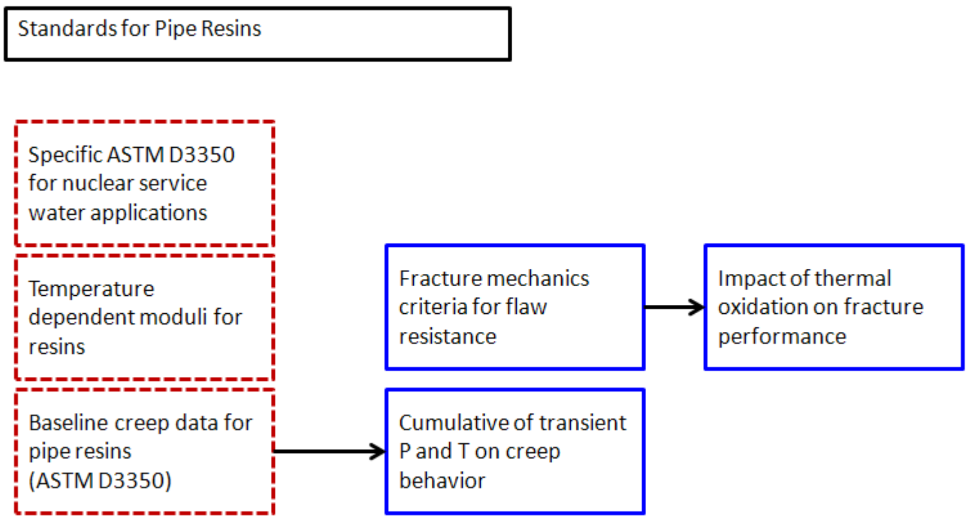

Figure 2: Connectivity for piping resin standards

Figure 2 shows connectivity for resin standards. In the short term, the specific properties required for HDPE resins used to manufacture piping for nuclear power plant service water applications would be drawn from ASTM D3350 in addition to the temperature dependent moduli for resins and specifications for carbon black content and marking standards. An additional step forward would be the development of baseline creep data for piping resins. Creep data would be employed to model long-term dimension changes and failure for service life prediction, but in the medium time frame used to understand the impact of transient stress (pressure) and temperature excursions on long time behavior. In addition, fracture mechanics measurements should be developed and standardized to measure slow crack growth initiation of flawed geometries to understand the flaw tolerance of viscoelastic resin formulations. This fracture mechanics based criteria would support an understanding of the performance of the resin, similar to the current PENT test, but providing a much richer data set to support modeling and design of piping systems. Once developed these standards provide a measurement platform that may be employed to understand the impact of thermal and chemical oxidation on crack growth over the lifetime of the resin material, which is relevant for antioxidant performance.

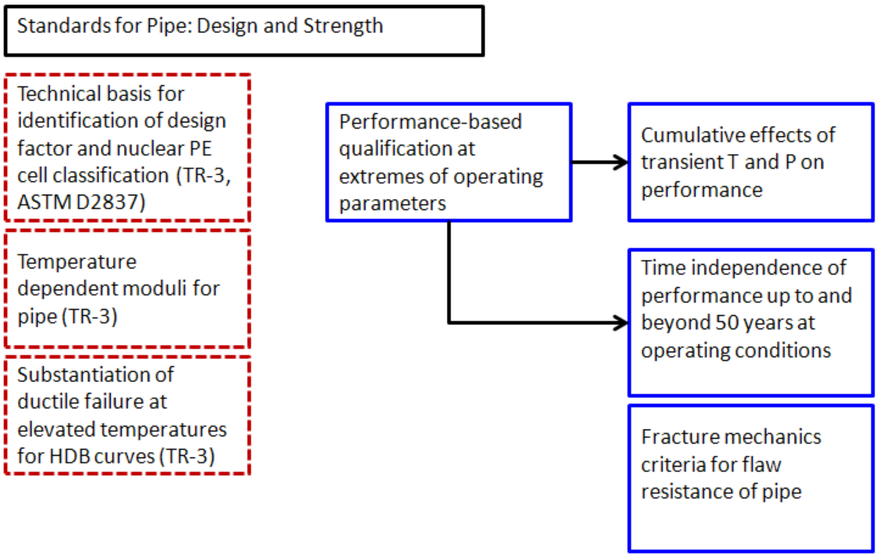

Figure 3: Standards connectivity for to determine the design and strength of piping materials

Following from Figure 2**,** standard gaps should be addressed for piping, particularly design and strength. In the short term, a methodology to identify the technical basis for the design factor should be developed for nuclear water piping applications. This will provide a path forward for stakeholders to change the design factor in the future. This has been discussed within the potable water community and pursued for PPI standards, it would serve to outline the technical basis needed by regulators to support a future change. There is overlap in the temperature dependent moduli of a piping related to the resin performance and the incorporation of the substantiation of ductile failure at elevated temperatures, currently 140 °F for these applications. The short term projects may inform the medium term, but are not directly connected for piping materials. In the medium term, a performance-based qualification should be developed for the extremes of operating temperature and pressure that is supported by a fracture mechanics understanding of failure for both pristine and flawed piping. In other words, how does pressure and temperature affect performance of both pristine and flawed piping? These standards in addition to the creep data provided for resins would verify the time independence of performance beyond 50 years within the design conditions. While TR-3 provides a method to determine the HDB and HDS beyond 50 years for pristine piping, the current code case has adopted a 50 year time limit. A technical basis will be needed by a regulator to remove that limitation.

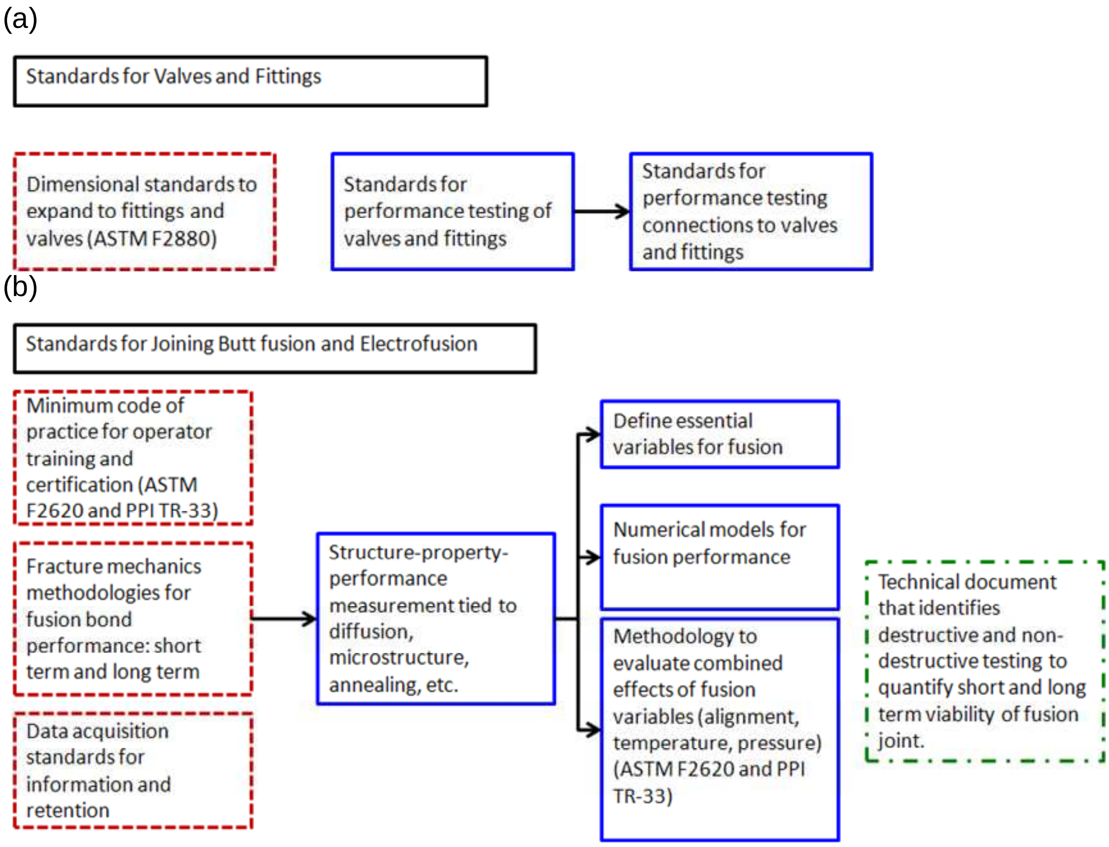

Figure 4: (a) Standards connectivity for valves and fittings and (b) Standards connectivity for joining through butt fusion and electrofusion

As the process moves from resins and pipings, connections must occur within the system, Figure 4a. These may be through physical connectors such as valves and fittings or welded connections such as junctions and taps. The standards path for valves and fittings is more straight-forward (Figure 4a), with a first step to developing dimensional standards to expand to fittings and valves. There are aspects of this process currently active within ASME and has led to the development of design equations for these devices that are available within ASTM beginning in 2012. The largest gap for fittings and valves concerns performance testing for valves, fittings, and connections between metallic and non-metallic components of the piping system. There are no polyethylene specific standards that address the measurement of slow crack growth for fittings and valves for long-term performance. The bulk of standards gaps were focused on the performance of fusion joints, Figure 4b. Within the current code case, the code of practice for operator training and data acquisition has been developed. This should be transferred to a standard document for future applications and permit updating as new technologies are delivered to the community. There is a critical need to develop a fracture mechanics methodology for fusion bonds to understand both the short and long term performance of a fusion joint. The development of this fracture mechanics methodology will support the development of structure-processing-performance required to understand the impact of diffusion, microstructure, and alignment on the performance of a fusion joint. The benefit of this knowledge is the capability to define a technical basis for the essential variables for fusion, develop numerical models, and sophisticated methodologies to understand the impact of imperfect conditions (T, P, alignment, flaw presence, ambient environment) on joint strength. Completing these tasks will lead to the long term goal of a technical basis for destructive and non-destructive testing to determine the short and long term viability of fusion joints. Fusion joints are critical because they represent the best method to guide non-destructive examination standards.

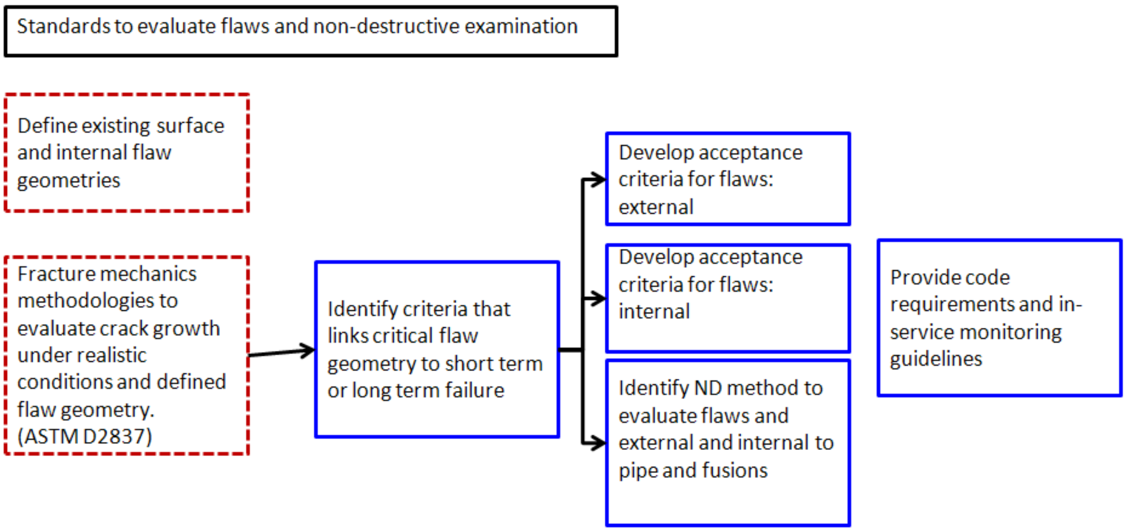

Figure 5: Standards connectivity for flaws and non-destructive examination

Figure 5 shows the process for developing standards for non-destructive examination. Initially, the community should understand the geometry of flaws produced in piping and from third party damage. This information may be gathered from piping present in the ground and current processing data for HDPE piping. The fracture mechanics methodologies developed to understand slow crack growth of flawed piping in Figure 3 may be used to determine which existing surface and internal flaws represent a threat for the health of a piping or fusion in the short and long term. This information will allow the community to develop acceptance criteria for internal and external flaws, which is critical to guiding the resolution and sensitivity requirements for the development of non-destructive testing for piping and fusions. The completion of these tasks will lead to code requirements for in-service monitoring. While many of these timelines have identified short and long term properties, more focus should be given to that specific endeavor since the long term performance of large diameter piping is critical for the success of HDPE within a nuclear power plant.

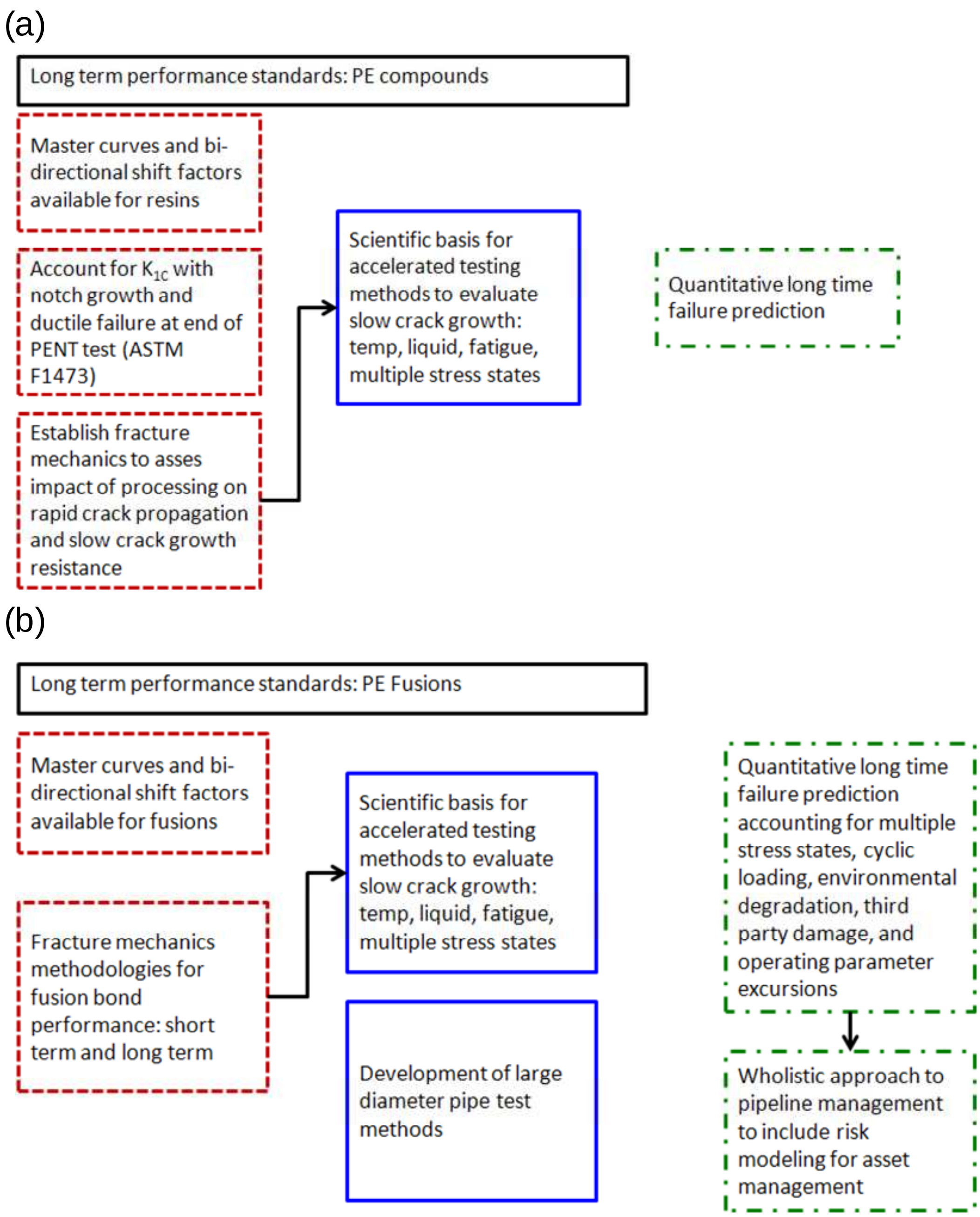

Figure 6: (a) Standards connectivity for long-term performance of HDPE compounds (such as resins and piping) and (b) Standards connectivity for long-term performance of HDPE fusions.

Figure 6 shows the map for long term performance of HDPE compounds (resins and piping) and fusions. The development of creep data for designers and manufacturers is an important step, but would be enhanced by the addition of bi-directional shift factors for the failure of piping materials and, if possible, fusion joints. The fracture mechanics based studies developed for resins and piping would be used to identify the impact of fusion and piping processing on short and long term performance, but also provide the community guidance on the best methods to accelerate failure. As the long term performance of piping has increased, it has become more difficult to accelerate failure to quantitatively determine the long term performance of the piping material. In fact, there are no quantitative service life prediction methods and standards available for HDPE piping and fusions. In addition, the testing utilized now do not easily measure the contributions of complicated stress states to failure that may occur in the presence of a flaw, joint, or fitting. An understanding of whether acceleration methods provide the same failure mechanism is important for developing a large diameter piping test or lacking that capability (due to expense or logistics) a substitute measurement of critical parameters for lifetime prediction. The long term vision shared through completion of these standards gaps is the development of a data, models, and measurements that provide quantitative lifetime prediction and support the development of a holistic approach to pipingline management. If the community is able to provide those capabilities, then utilities and regulators will be able to efficiently and economically manage the system well beyond the 60 year lifetime.

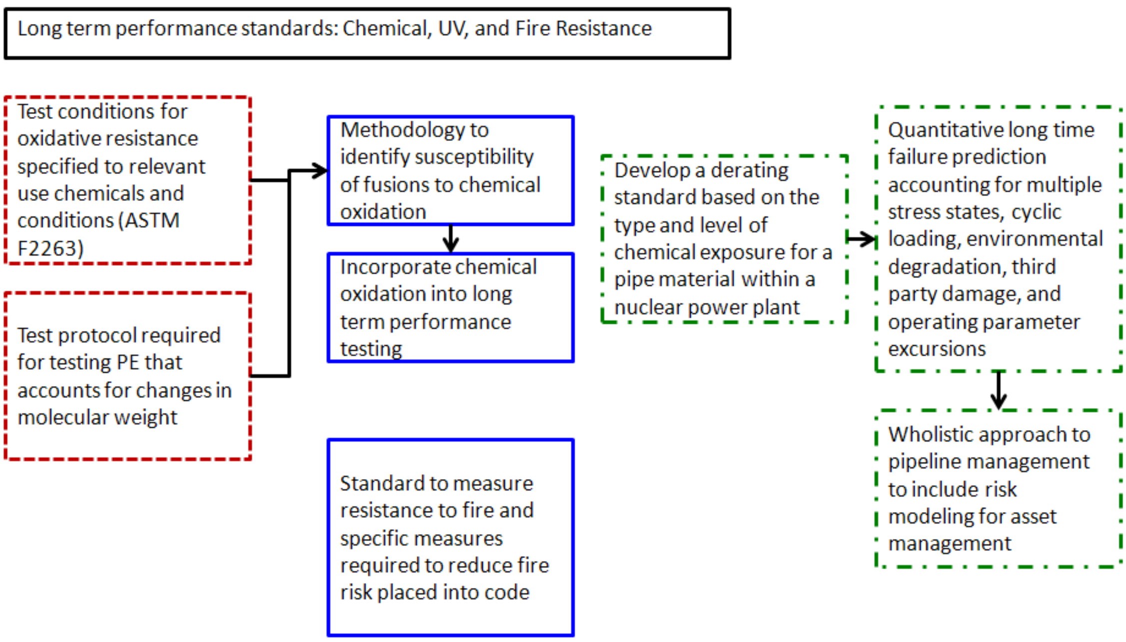

Figure 7: Standards connectivity for long-term performance under environmental stressors

Within long term performance standards is a sub-category regarding environmental stresses and outside threats. This area does not provide the comprehensive understanding for HDPE piping that has been given to piping design and long term performance to date. Specifically, standards for chemical resistance do not address the types of oxidants a nuclear power plant would utilize for cleaning the system (i.e. bromine or permanganate) and they focus on the presence of antioxidants while limiting the understanding of how the piping material may continue to oxidize once the antioxidants are lost. The loss of antioxidants leads to surface embrittlement and cracking. Better measurements and standards for chemical oxidation and a connection to long term failure would identify whether surface cracks present a threat for slow crack growth failure. These methods will translate to an understanding of whether bulk failure testing currently provides resolution of the oxidative failure transition. Therefore, standards should be developed to identify the susceptibility of fusions and piping to nuclear power plant specific oxidants with a focus on the presence of antioxidant and the impact of degradation on slow crack growth resistance. These could further be used to develop a derating standard based on the type and level of chemical exposure expected for the pipingline. Similarly, UV and fire resistance have not been given adequate representation. UV resistance has been addressed for municipal water supplies, but this has not been carried over to large diameter piping. A standard should be adopted/developed to measure the fire resistance of piping and utilized to evaluate fire suppression/resistant strategies. EPRI has conducted work in 2011 and 2012 to measure the performance of several fire resistance strategies. The ultimate long term goal is to account for these oxidants within the scope of lifetime prediction to provide stakeholders the ability to assess the risk of failure for the system throughout its lifetime.

The next section provides a breakdown of the specific gaps and how those might be addressed within the timeframe provided above by either SDO's, regulators, utilities, and academia.

7.2 Short Term Gaps (< 3 yrs)

7.2.1 Standards for Piping Resins

The main gap is the broad nature of ASTM D3350. The specifications for resins in the code case are narrower than those given in this standard. Reducing the number of specifications to those required for manufacture of piping specifically for nuclear applications will reduce the chance for confusion or unnecessary testing. This is a gap that can be handled with the framework of an SDO such as ASTM in conjunction with ASME.

7.2.2 Standards for Design Basis and Strength

ASME Code Case N-755 utilizes a conservative design factor (DF) of 0.5 compared to the design factor of 0.32 to 0.40 used in the natural gas industry and the less conservative 0.63 used in the water industry. This conservative approach is a consequence of the cell classification for HDPE 4710 developed through ASTM D2837. If a higher DF is desired, a technical basis will be required to support a new DF. This may be accomplished by tabulating the factors that affect the design factor such as material variability, production variability, design condition variability, etc. Reinhart[19] has done this, but this type of support is often composed of empirical experience rather than validated measurements conducted using standard test methods required for the development of a technical basis. Another method is the development of a new cell classification or design factor through the HDB/HDS standards that reflects the higher performance HDPE materials for nuclear applications.

[19] Reinhart, F; "Whence cometh the 2.0 design factor" letter from PPI (1994).

Both of the ASTM and ISO methods provide a conservative estimate of the long-term hydrostatic strength, which is then combined with a design factor. The HDB curve requires substantiation of linearity by using elevated temperature testing to validate ductile failure extrapolation. HDPE has been treated in the ASME Code Case N-755 as if it will be exposed to an elevated temperature throughout the design life, with the potential for temperature excursions. Currently, substantiation to 50 yrs is not conducted at this elevated temperature. Substantiation of linearity should be conducted as part of the development of a piping material for nuclear operation. This could be quickly accomplished through the current path of ASTM and PPI to incorporate a substantiation mechanism.

7.2.3 Standards for Joining

Butt fusion and electrofusion processes

These two joining methods have similar gaps, which may be addressed in the short term. In fact, some of these are already addressed within the framework of ASME Code Case N-755. A minimum code of practice for operators is needed for training and certification of fusion machine operators. This will reduce variability between fusions and operators. This code of practice should be developed within the framework of ASME, the nuclear industry, and the NRC.

Similarly, a technical document specific to the type of piping, SDR, piping/resin manufacturer, and fusion machine should be developed. This document would specify the essential variables for fusion and provide traceability for why those variables were chosen. While the issue is currently resolved within the SDO community, there remain questions pertaining to regulatory requirements. These specifications should continue to be addressed during code case development and research opportunities identified, if required to satisfy regulatory requirements.

Acquisition and storage of fusion data is critical for maintaining the system over the long term and identifying trouble spots in the case of an accident. The ASME Code Case N-755 specifies a data acquisition sheet, but there is no single acquisition standard for the required data acquisition. Data acquisition should be formalized through the ASME, ASTM, and U.S. NRC process.

7.2.4 Standards for HDPE Compounds

Specific changes should be made when concerning samples generated for long time testing. These include changes to ASTM D1473 which describe the impact of processing samples (piping vs. compression mold) on failure times, appropriate methods to section and test thick piping to account for residual stress or microstructure gradients, methods to account for changes in stress intensity with crack growth in notch testing, and methods to account for or remove samples that exhibit ductile failure at the end of the test. These gaps can be addressed through support of additional research to address sample preparation questions. Calculations of stress intensity and ductile failure may be handled within the ASME and ASTM framework.

7.2.5 Standards for HDPE Piping

ASTM D3035 does not specify ASTM F1473, but it does specify ASTM D1598. ASME Code Case N-755 requires both notch testing of HDPE resins and hydrostatic testing of piping. Referencing all testing required for nuclear plant applications can improve efficiency of standards.

ASTM D1598 does not fully specify initial water chemistry or tracking of water chemistry throughout exposure. In addition, the flow through piping should be specified since this is an important parameter for testing long-term behavior of HDPE piping.

7.2.6 Standards for NDE Testing of Volumetric Flaws

There are multiple techniques available to measure the characteristics of volumetric flaws, but additional research is needed to specify the critical dimensions of a volumetric flaw. These critical dimensions should be related to the pressure and temperature the piping or fitting will experience during the design life. The critical dimensions should be specified to reflect the risk of failure for the piping or fusion joint in both the short and long term strength. When the critical dimensions are specified, piping, fittings, and valves with standard flaws may be generated to benchmark NDE techniques and provide a target resolution for these emerging methods. A standard evaluation protocol should be developed in ASME to train personnel and evaluate/accept new non-destructive technologies.

7.2.7 Develop HDB/HDS at Long-times

The HDB curve requires substantiation of linearity by using elevated temperature testing to find the knee in the ductile failure curve or at least verify the failure remains ductile and has not transitioned to brittle-like failure. HDPE is treated in the code case as if it will be exposed to an elevated temperature and constant pressure throughout the full design life. It has become apparent that this temperature represents an extreme and brief excursion of operating parameters. There is survey data of plant safety-related water operating conditions available from the Electric Power Research Institute (EPRI) that indicates continuous use temperatures are closer to 100 °F. This does not include seasonal changes in operating temperature. Currently, substantiation is not conducted at this elevated temperature to determine the HDB for the current HDPE resin. Substantiation of linearity in the ductile failure envelope at elevated temperature should be conducted as part of the development of a piping material for nuclear operation. This could be accomplished through the current path of ASTM and PPI to incorporate a substantiation mechanism based on the current protocols of ASTM D2837 and TR-33.

7.2.8 Standards for Chemical Resistance

ASTM F2263 should be modified to specify the exposure test conditions to measure the oxidative resistance of HDPE piping to chlorinated water and this should be linked to specific water conditions within the nuclear plant. This may be handled in the ASME and ASTM process with plant water chemistry data provided by the nuclear industry via EPRI.

ASTM F2263 should develop a test protocol that is specific to nuclear HDPE resins with specific test procedures and methods. The current HDPE resin used in nuclear industry water systems is sufficiently different from unimodal (MDPE and LDPE) and non-nuclear bimodal resin materials that it requires a specific test protocol. This gap may be addressed through the ASTM process with input from resin manufacturers and PPI.

The American Petroleum Institute (API) addresses chemical resistance through the introduction of classes of chemicals in standard API 17 TR2. The class is determined by a fit of the time to reach a minimum dynamic toughness value at a specific temperature. Increasing the class number is indicative of a more severe chemical. A system that ties piping risk to severity of chemical exposure will increase the efficiency of asset management systems. While the API standard can serve as a foundation for a new standard, new research on the specific chemical risk to nuclear plant specific chemicals is required.

ASTM D2837 develops the HDB/HDS curve utilizing water, many times de-ionized. The pure water chemistry in this test can impact the failure time by reducing the oxidation of the piping wall or altering the diffusion rate of anti-oxidant additives from the piping wall. ASTM F2263 should provide a test method to account for the combined effects of oxidative attack and accelerated failure in the determination of the HDB/HDS curve. This gap should be addressed by further research to define a suitable test method with a clear understanding of the test limits and error at the University or Government Institute level. This test method would be incorporated into the standard and potentially a chemical class system through the ASTM and ASME process.

7.2.9 Other Standards Gaps

Piping Hangers and Supports

Buried piping is expected to transition from a buried system to an above ground system within the plant. Once the piping is above ground, it must be supported through a system of hangers and supports. This may also be the case for pipings that are within a buried trench and that could be inspected from the outside (i.e. not covered with backfill). In addition, bracing systems should also be considered in conjunction with hangers and supports; especially regarding seismic, wind, thermal expansion, and dynamic loading. The ANSI/MSS SP-58-2009 standard has been developed to address many of the design and installation needs for piping infrastructure support, including water. MSS should be encouraged to address any standard gaps within the next version of SP-58, based on NRC and/or nuclear industry needs for piping hangars and supports.

Seismic Design

ASME Code Case N-755 provides equations for Nonmandatory Seismic Analysis for piping design in Appendix D. Guidance for seismic design is provided in the ASME B31E-2008 section code. A standard for seismic design should be developed that reduces any redundancy and specifies the differences between the needs of the nuclear industry and the ASME B31.1 code. This gap should be addressed through the ASME, ASTM, U.S. NRC code approval process. This should include the design of fitting and valves within the piping system. If the performance of thick section HDPE piping or fitting is not sufficiently known, than research should be funded to develop validated models that would guide standards development. EPRI has conducted seismic analysis of HDPE piping systems, for use in aboveground applications, to measure material properties relevant to seismic design[20].

Seismic design should also include bracing piping for wind and seismic threats as piping transitions into the nuclear plant infrastructure. MSS SP-127 *Bracing for Piping Systems Seismic-Wind-Dynamic Design, Selection, Application* was first published in 2001 and has specific relevance to seismic, wind, and other dynamic elements pertinent to piping systems and their stabilization within the nuclear industry. This standard continues to be available from MSS and could be reinstated based on NRC and/or nuclear industry needs, in tandem with, or complimentary with ASME B31.1. MSS should be encouraged to address any standard gaps within the next version of SP-127, based on U.S. NRC and/or nuclear industry needs and process.

Fire Resistance

While the majority of buried HDPE piping may reside underground, where the risk of fire is minimal, sections that are above ground will be at risk of fire[21]. Standards should be developed to determine the fire resistance of HDPE materials, especially the design parameters in the event of a fire or explosion within the plant. Standards should be developed to specify suitable fire resistant coatings for these resin systems, in the event that large diameter HDPE piping does not provide a sufficient safety factor for fire fighting. EPRI has investigated the performance of polyethylene piping protected by a fire-resistance wrapping[22] and subjected to fire conditions according to ASTM E119[23] and hose stream conditions of ASTM E2226[24]. Finally, any additional coatings applied to the piping must be tested according to standards that address adhesion, flexibility, thermal conductivity, impact performance, and fire performance.

7.3 Medium Term Gaps (3 - 8 yrs)

7.3.1 Standards for Design Basis and Strength

The code case sets the design life at 50 yrs. Under certain design conditions, the piping could last longer than 50 yrs. A new standard or documentation should be developed to determine the time-

[20] "Seismic properties for high-density polyethylene piping for use in above-ground applications" Product ID: 1021095; EPRI (2011)

[21] Fire risk does remain for piping that resides in tunnels, trenches, and vaults. Therefore, fire resistance is important for these applications.

[22] "Fire Testing of High-Density Polyethylene Piping" Product ID: 1023004; EPRI (2011)

[23] ASTM E119-12 "Standard test methods for fire tests of building construction materials" ASTM International, West Conshohocken, PA 2012

[24] ASTM E2226-11 "Standard practice for application of hose stream" ASTM International, West Conshohocken, PA 2011

independence of performance up to and beyond 50 yrs at the use conditions. This would be in addition to substantiation at elevated temperature. One challenge that remains is the availability of test methods that measure long term failure in a reasonable test time. An example of a method to address this challenge is the recent development of a cracked round bar (CRB) fatigue or creep tests for the measurement of slow crack growth (SCG) at elevated temperature. This gap should be addressed by leveraging the most recent research available on SCG measurement in HDPE piping. Validation of any selected test method should be conducted between Industry and recognized independent laboratories with results available for the U.S. NRC.

One remaining challenge is the expectation of continuous elevated temperature service over the 60 yr service time of a nuclear power plant. These systems are utilized intermittently, which means design for continuous elevated temperature could be an overestimate of failure time. A step to refine failure time is to measure the RPM coefficients and creep data for nuclear HDPE piping resins. Other options would include cyclic pressure testing of piping. This data would be utilized to develop models that predict piping lifetime based on pressure and temperature excursions over the lifetime of the piping. New standards would need to be developed to address the use of these models or test methods.

7.3.2 Standards for Valves and Fittings

Standards should be expanded to include the design of additional fittings and valves. Any fitting and valves standards should include validated temperature and pressure derating tables. The derating factors should be referenced to test results available in the open literature. In addition, these standards should account for the application of hybrid systems that include both polymer and metal components. The standard should be addressed in the ASTM and ASME process, since many of the basic design and derating procedures are available for the water and gas industry.

A standards gap remains in the measurement of SCG in fittings. The complex stress states in the geometry of valves and fittings have the potential to accelerate SCG. Any standards developed for valves and fittings should include the procedure to determine the long term HDB and HDS for the fitting and valve. This gap should be addressed through further research to determine the critical dimensions that accelerate SCG and these limits specified in the standard. The standard should be developed in the ASME and ASTM process.

7.3.3 Standards for Joining

Butt fusion and electrofusion processes

These two joining methods have similar gaps, which may be addressed in the medium term. Current standards subject joints to a multitude of stress states (tension, notch testing, and bend back testing) and time scales (quasi-static, hydrostatic, and impact) for performance testing. There are no standards that address the effect of multiple stresses on joint strength. An example is the impact of misalignment, fitting tolerances, and ambient conditions on joint performance in the short time and long time. Standards should be developed that address combined effects on performance. Since the combination of parameters is staggering, further materials research combined with perturbation analysis is needed to define the fusion test method. This standard method would be developed in the ASME and ASTM process.

Coupling non-metallic materials to metallic materials has been done in the processing and oil and gas industry. HDPE piping will be required to mate to existing metallic lines within the nuclear plant. The community should be aware of situations that would require coupling dissimilar materials and identify standards earlier rather than later. MSS SP-107 *Transition Union Fittings for Joining Metal and Plastic Products* is a withdrawn standard that addresses some of these issues. This standard could be revisited based on NRC and/or nuclear industry needs and process or provide material for another standard provided MSS is aware of the need to revisit the standard. In addition, PPI TN-36 *General Guidelines for Connecting HDPE Potable Water Pressure Pipings to Ductile Iron and PVC Piping systems* covers flanged connectors, solid iron sleeves, and bell adapters.

7.3.4 Standards for HDPE Compounds

The current standards do not specify how to test fusion specimens generated from resin materials for SCG measurements. This includes machining specimens from piping, inserting notches, and verifying the location of failure within the fusion zone. ASTM D1473 should be updated to address fusion joint preparation and testing. Measurements are needed to verify crack propagation within the interface and not within the body of the piping. This gap would require further research to measure the error induced via test sample preparation and methods to verify that sample preparation (cutting, molding, extrusion) does not influence results. ASTM D1473 would be updated through the ASME and ASTM process.

7.3.5 Standards for HDPE Fusions

Research should be supported to develop a specific standard test method for HDPE fusions, especially those used to generate fittings. There are techniques within the academic literature that show promise to capture joint quality, but these need to be developed into a test standard. Short term testing should be limited to those tests that test specific modes of failure or stress induced failures (e.g. Mode I, Mode II, or mixed Modes) experienced by fusion joints during service.

7.3.6 Standards to Evaluate Surface and sub-Surface Flaws

There are currently no standards to characterize surface flaws in piping. Standard methods should be developed to quantify flaw dimensions and train personnel to evaluate flaws in the field. The risk of failure in both short term and long term should be identified for flaws based on geometry, location, and piping service environment. This will require additional research to identify the most common flaw geometries both within fusions and extruded large diameter piping. Statistical models that allow operators to quantify the risk of failure will be needed to assign a risk factor and guide repair/removal decisions to facilitate efficient plant asset management.

7.3.7 Standards for Ultraviolet and Ionizing Radiation

HDPE piping is often exposed to ultra-violet radiation during shipping, while awaiting installation, and transitioning from below ground. The intensity of radiation, time of exposure, and resin additives are critical for minimizing damage. Standards should be adopted to verify the performance of HDPE resins after prolonged exposure. This information has been available in the water and gas industry, but results specific to nuclear industry HDPE should be compiled and evaluated to determine whether more research is required to specify an accelerated UV exposure test.

Similarly, a standards gap exists concerning radiation exposure. The nuclear industry and regulators should identify the potential radiation type and dosage range. While current implementation of HDPE is not intended for exposure to damaging levels of radiation, a gap for verification of durability under ionizing radiation exists. This information may be used to direct future research into standards development. The ASME and NRC may address this gap.

7.4 Long-term Gaps (> 8 years)

7.4.1 Standards for HDPE Compounds, HDPE Piping, and HDPE Fusions

The significant long-term standards challenge is the inability to incorporate data generated in long time testing into predictive models. This leads to a standards gap where long time data must be generated for each resin and potentially each application. For example, ASTM F1473 for PENT (Pennsylvania Edge Notch Test) is not a service life predictor. It is only an index test for HDPE compounds to rank one to another for this type is slow crack growth performance. Granted, the industry has come to understand that in general a higher PENT performance could lead to a longer potential service life, it is certainly not a “predictor” of service life. The ASME Code Case N-755 has provided that a HDPE compound must have a 2000 h PENT performance, but there has been limited information to determine what this actually means to the potential service life. This is a gap that should be studied. Even ASTM D2837 and ISO 9080 are not lifetime prediction methods. They are long-term hydrostatic strength determination methods. These results can be used to assign a “lifetime” to the material, but it is erroneous and that terminology should be avoided. This would be similar in metallic piping to identify the tensile strength as the sole determination of lifetime – which is not true. The metallic materials’ ability to withstand corrosion and fatigue are better indicators. The same is true for HDPE compounds. The HDB is the strength and the allowable stress values are not considered time dependent. Other factors, such as the ability of the material to shed localized stress intensifications, and the oxidative environment should be included in estimates of a service “lifetime”. A standardized test to generate long time data that supports predictive models for quantitative service life would close this gap. This will require significant research to identify a quantitative lifetime prediction test and associated predictive models.

7.4.2 Standards for Chemical Resistance

A standard gap exists for the derating of HDPE piping performance based on exposure to degradative chemicals. This includes both continuous exposure, cyclic exposure, and exposure at elevated temperatures. This standard gap should be addressed through the identification of the specific chemicals within the nuclear plant. The short term standard gap that addresses exposure limits and test conditions would be utilized to formulate the derating system which would be introduced into the ASTM standard for chemical resistance

7.4.3 Incorporation of New Piping Materials

This standards evaluation report has focused on HDPE piping applications. There are other classes of materials used within the natural gas and oil industry that can provide additional capabilities to the nuclear industry in high temperature and pressure applications. In order for the nuclear industry to take advantage of these materials, each material will be subjected to the code case process. It is critical that the lessons learned from ASME Code Case N-755 are translated to a roadmap for bringing new piping materials online. This will allow the efficient collection and evaluation of current standards and available data sets to organize technical basis documents before and during the code case process.

8 Summary

The PPTG conducted a comprehensive review of standards related to HDPE piping for nuclear applications. This review of standards identified gaps that could be filled within a reasonable time frame. In some cases, the gaps require only a better specification of procedures to greatly increase the relevance and quality of the existing standard. In other cases, a program to address gaps in the current understanding of HDPE performance must be addressed through the development of new materials science and measurements. The PPTG has provided guidelines to address standards gaps and the increased performance requirements for nuclear piping. The implementation and prioritization should be developed between operators, regulators, and SDO organizations. This is especially true where the gaps are related to increasing material performance or acceptance requirements rather than the development of a new standard. Increases in performance and acceptance requirements are often explicitly stated within the code in order to maintain broad applicability of standards. This can reduce efficiency since it requires maintenance of a significant database of documents related to specification, design, and quality assurance/quality control.

While this standards review was focused on HDPE piping, the gaps identified should apply to other non-metallic piping materials and systems. The main lessons learned were that many of the questions developed in a code case can be answered when validated technical data is available to the industry and regulators concerning the specific materials, intended design specifications, and environmental conditions. This technical data is crucial for the development of the technical basis for design and supporting the development of code requirements. The best method to generate this data efficiently and in a manner that is accepted by material manufacturers, operators, and regulators is through the development of current and relevant standards.

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Appendix A

NESCC Request for PPTG

At the May 26, 2010 NESCC meeting, a new Task Group was established to work on Piping for Nuclear Standards. As a result of this establishment, the NESCC Is issuing a call for membership. Below you will find the initial scope of the Task Group and the contact information for the convener of the group. If you are interested in joining the Task Group, please reply to this email and include your full contact information. This information will be forwarded to the Task Group Convener.

Piping for Nuclear Power Plants Task Group

Scope (as defined in NESCC 10-006):

- Establish coordination and consistency of safety and non-safety related polymer piping requirements in nuclear power plants;
- Identify and review all NRC regulatory documents related to polymeric piping for nuclear power plants;
- Identify and review all ASTM, AWWA and PPI standards related to polymeric piping safety water applications;
- Identify ancillary standards needed to certify manufacturers and the installation and inspection of piping

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Appendix B

These following tables provide a summary of ASTM standards concerning material property and performance characterization of various thermoplastic, thermoset, and composite materials that are present in piping systems. The Non-Metallic working group within Section III of ASME kindly provided them to the PPTG for publication within this report. The PPTG would like to thank ASME for providing this information. Missing standards or incomplete sections have been removed from this publication in order to provide a complete table

Table B- 1: Level 1 – Mechanical Engineering Property Issues

	Constituents ---thermoplastic ---thermoset ---reinforcements	Fiber-reinforced Polymers ---lamina ---laminate ---bulk	Graphite & Impregnated Graphite
Tensile Strength[a,b]	ASTM D3039 ASTM D638 ISO 527	ASTM D3039 ASTM D638	ASTM D3039
Modulus[a,b]	ASTM D638	ASTM D3039	ASTM D3039
Poisson Ratio[a,b] --ν_{12}, ν_{13}, ν_{23}, et al	ASTM D638	ASTM D3039	
Shear Strength[a,b]		ASTM D5379 ASTM D 4255 ASTM D 3518 ASTM D 2344	
Shear Modulus[a,b]		ASTM D 5379 ASTM D 4255 ASTM D 3518 ASTM D 2344	
Coefficient of Thermal Expansion[a,b]	ASTM E 831	ASTM E 831	
Fracture Toughness[a,b]		ASTM D5528	
General Immersion[a]	ASTM D543	ASTM D543	
Creep & Creep Rupture[a,b] --compressive --tensile --flexural	ASTM 2990		
Impact[a,b]	ASTM D1599 ASTM D3763 ASTM D6110 ASTM D5628		
Cyclic Loading[a,b]			
Flexural Strength & Modulus[a,b]	ASTM D790 ASTM D6772 ISO 178		
Compressive Strength & Modulus[a,b]	ASTM D2583 ASTM D695 BS EN 59 ISO 868	ASTM D3410 ASTM D6641	

Note "a" – all of these will apply to various temperatures, moisture content, and loading rates.
Note “b” – all of these are orientation dependent.

Table B- 2: Level 1 - Material Methods for Thermo-plastic Polymers

	Polyethylene	Polypropylene	Chlorinated PVC	PVC	Acetal
Tensile Strength[g]	ASTM D3039 ASTM D638 ISO 527	ASTM D3039 ASTM D638 ISO 527	ASTM D3039 ASTM D638 ISO 527	ASTM D3039 ASTM D638 ISO 527	ASTM D3039 ASTM D638 ISO 527
Modulus[g]	ASTM D3039	ASTM D3039	ASTM D3039	ASTM D3039	ASTM D3039
General Immersion[g] (pH)	ASTM D543	ASTM D543	ASTM D543	ASTM D543	ASTM D543
Creep Rupture[g]	ASTM 2990 ASTM 2992	ASTM 2990 ASTM 2992	ASTM 2990 ASTM 2992	ASTM 2990 ASTM 2992	ASTM 2990 ASTM 2992
Tensile Impact[g]	ASTM D1599	ASTM D1599	ASTM D1599	ASTM D1599	ASTM D1599
Cyclic Loading[g]					
Flexural Strength & Modulus[g]	ASTM D790 ISO 178	ASTM D790 ISO 178	ASTM D790 ISO 178	ASTM D790 ISO 178	ASTM D790 ISO 178
Compressive Strength & Modulus[g]	ASTM D2583 BS EN 59 ISO 868	ASTM D2583 BS EN 59 ISO 868	ASTM D2583 BS EN 59 ISO 868	ASTM D2583 BS EN 59 ISO 868	ASTM D2583 BS EN 59 ISO 868

Note "g" – all of these will apply to various temperatures.

Table B- 3: Level 1- Material Methods for Fiber-reinforced Polymers & Thermo-set Polymers

	Epoxy	Polyester	Furan	Phenolic / Novolac	Polyurethane
Tensile Strength[g]	ASTM D3039 ASTM D638[b] ISO 527	ASTM D3039 ASTM D638 ISO 527	ASTM D3039 ASTM D638 ISO 527	ASTM D3039 ASTM D638 ISO 527	ASTM D3039 ASTM D638 ISO 527
Modulus[g]	ASTM D3039 ASTM D638	ASTM D3039 ASTM D638	ASTM D3039 ASTM D638	ASTM D3039 ASTM D638	ASTM D3039 ASTM D638
General Immersion[g] (pH)	ASTM D543	ASTM D543	ASTM D543	ASTM D543	ASTM D543
Creep Rupture[g]	ASTM 2990 ASTM 2992	ASTM 2990 ASTM 2992	ASTM 2990 ASTM 2992	ASTM 2990 ASTM 2992	ASTM 2990 ASTM 2992
Tensile Impact[g]	ASTM D1599	ASTM D1599	ASTM D1599	ASTM D1599	ASTM D1599
Cyclic Loading[g]					
Flexural Strength & Modulus[g]	ASTM D790 ISO 178	ASTM D790 ISO 178	ASTM D790 ISO 178	ASTM D790 ISO 178	ASTM D790 ISO 178
Compressive Strength & Modulus[g]	ASTM D2583 BS EN 59 ISO 868	ASTM D2583 BS EN 59 ISO 868	ASTM D2583 BS EN 59 ISO 868	ASTM D2583 BS EN 59 ISO 868	ASTM D2583 BS EN 59 ISO 868

Note "g" – all of these will apply to various temperatures.

Note “b” – although ASTM D3039 is the preferred industry standard, ASTM D638 is acceptable for some materials