AmerenUE
Callaway Plant

PO Box 620
Fulton, MO 65251

July 10, 2008

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Mail Stop P1-137
Washington, DC 20555-0001

ULNRC-05517

Ladies and Gentlemen:

DOCKET NUMBER 50-483
CALLAWAY PLANT UNIT 1
UNION ELECTRIC COMPANY
FACILITY OPERATING LICENSE NPF-30
10CFR50.55a REQUEST: PROPOSED ALTERNATIVE
TO ASME SECTION XI REQUIREMENTS FOR
REPLACEMENT OF CLASS 3 BURIED PIPING – (TAC NUMBER MD6792)

References: 1. ULNRC-05434 dated August 30, 2007
2. ULNRC-05490 dated April 17, 2008
3. NRC Request for Additional Information (RAI) letter from Mohan C. Thadani to Charles D. Naslund dated June 10, 2008

In Reference 1 cited above, and in accordance with 10CFR50.55a, Union Electric Company (AmerenUE) submitted Relief Request I3R-10 regarding paragraph IWA-4221(b) of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI. The relief requested per I3R-10 is needed to support the planned replacement of buried steel piping in Callaway's essential service water (ESW) system with high-density polyethylene (HDPE) piping. For this repair/replacement activity, IWA-4221(b) would require the new/replacement piping to meet the original Construction Code requirements for the ESW piping. The applicable Construction Code (ASME Section III), however, does not provide rules for the design, fabrication, installation, examination and testing of HDPE piping, and therefore, AmerenUE requested relief from the noted Code requirements. [The ASME Section XI Code Edition applicable to the current 10-year Inservice Inspection interval for Callaway Plant is the 1998 Edition (up to and including the 2000 Addenda).] AmerenUE's relief request is still under review by the NRC staff.

In Reference 2, AmerenUE responded to questions received from the NRC's Piping and NDE Branch (CPNB) and Mechanical and Civil Engineering Branch (EMCB) regarding the relief request. More recently, additional questions/requests were identified by the NRC staff and were transmitted in a request for additional information (RAI) identified as Reference 3 above. The questions/requests of the

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Reference 3 RAI letter were contained within five enclosures to the letter. The questions/requests contained in Enclosures 1 and 2, in particular, were provided from the NRC's Division of Component Integrity and Division of Engineering, respectively. AmerenUE is hereby providing its responses to those questions/requests. Responses for the questions/requests contained in Enclosures 3, 4, and 5 of the Reference 3 RAI letter are being transmitted under a separate cover letter from AmerenUE, i.e., AmerenUE letter ULNRC-05520.

In response to the NRC's RAI letter, Enclosure 1 of this letter contains responses to the questions/requests from the NRC's Division of Component Integrity, and Enclosure 2 provides responses to the questions/requests from the NRC's Division of Engineering. Supporting information for the responses is provided in additional enclosures to this letter. Specifically, a letter from Dow Chemical Company (with its own attachments) is provided in Enclosure 3. Enclosure 4 contains a calculation of the minimum wall thickness for the subject underground HDPE piping, i.e., Callaway Calculation 2007-13241. (The calculation is not finalized but will be available for inspection after finalization.) Enclosure 6 provides information that supports the response to one of the RAI questions addressed in Enclosure 2. It provides a basis for use of a 0.56 design factor in the determination of allowable stresses for the HDPE piping design. Enclosure 7 provides a summary of the commitments made within this submittal.

In addition, in developing the responses for the NRC's RAI, it was determined that the relief request document itself (as originally provided via Reference 1) must be revised. An updated and final version of the relief request, i.e., 10CFR50.55a Request Number I3R-10, is therefore provided as Enclosure 5 to this letter. The revised relief request has its own attachment, "Requirements for HDPE Piping for Nuclear Service," which is included within Enclosure 5.

If you have any questions on this letter or its enclosures, please contact Mr. Scott Maglio at (573) 676-8719.

Very truly yours,

Keith A. Mills 10 July 08

Keith A. Mills
Manager – Plant Engineering

GGY/MDB/TBE/nls

Enclosures: 1 – Responses to RAI Questions/Requests from NRC Division of Component Integrity
2 – Responses to RAI Questions/Requests from NRC Division of Engineering
3 – Letter from Dow Chemical Company (with attachments)
4 – Callaway Calculation No. 2007-13241
5 – 10CFR50.55a Request Number I3R-10 (with attachment)
6 – Justification for Increase in Callaway's HDPE Design Factor
7 – Summary of Regulatory Commitments

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Enclosure 1

Responses to RAI Questions/Requests
from NRC Division of Component Integrity

OFFICE OF NUCLEAR REACTOR REGULATION

REQUEST FOR ADDITIONAL INFORMATION

RELATED TO ESSENTIAL SERVICE WATER

UNION ELECTRIC COMPANY

CALLAWAY PLANT

DOCKET NO. 50-483

The Division of Component Integrity staff has reviewed the licensee's response to the Nuclear Regulatory Commission (NRC) staff's first round of request for additional information (RAI). Based on that review, the NRC staff has a need for additional information. Accordingly, a second round of RAIs was sent to the licensee via e-mail on June 2, 2008, and is being formally documented here for response.

As stated above, the NRC staff requests a response to the following second round of RAIs.

1. Title 10 of the Code of Federal Regulations (10 CFR) Appendix B, Criterion XVII, Quality Assurance Records, states, "Records shall be identifiable and retrievable." The Standard Fusion Procedure Specification (FSP) in QF-221 implies that the supporting records exist in the Plastic Pipe Institute (PPI) report TR-33/2001. The data used in TR-33/2001 is based on limited tests and equipment manufacturer recommendations. The information supplied in Callaway's request does not provide record traceability and record retrievability that support the FSP qualification tests.

Question/Request:

Provide a discussion on the accessibility of records supporting the procedure, equipment, and personnel qualifications that will be used for installation and examination of high density polyethylene (HDPE) pipe.

Response:

Background

Background information needs to be provided to answer this question. First, TR-33 was written to address 49 CFR 192.283 (Federal safety standards for transportation of natural and other gas by pipeline):

Sec. 192.283 Plastic pipe:

(a) Heat fusion, solvent cement, and adhesive joints. Before any written procedure established under Sec. 192.273(b) is used for making plastic pipe joints by a heat fusion, solvent cement, or adhesive method, the procedure must be qualified by subjecting specimen joints made according to the procedure to the following tests:

(1) The burst test requirements of--

(i) In the case of thermoplastic pipe, paragraph 6.6 (Sustained Pressure Test) or paragraph 6.7 (Minimum Hydrostatic Burst Pressure (Quick Burst)) of ASTM D 2513…

(3) For procedures intended for nonlateral pipe connections, follow the tensile test requirements of ASTM D638, except that the test may be conducted at ambient temperature and humidity. If the specimen elongates no less than 25 percent or failure initiates outside the joint area, the procedure qualifies for use.

During the initial development process of TR-33, two parameters were found to be critical: interfacial pressure (60-90 psi) and fusion temperature (Heater Plate) of 400-450° F. Pipe size or wall thickness was determined not to be a critical variable.

(Heater) Temperature

The temperature is critical not only for the material but the fusion process as well. If the temperature is higher than 450° F, damage to additives in the base material may occur thereby reducing the material properties. Also, a high temperature could cause excessive melted material to flow out of the joint when pressure is applied creating a poor quality joint. Low temperatures could result in incomplete fusion.

Interfacial Pressure

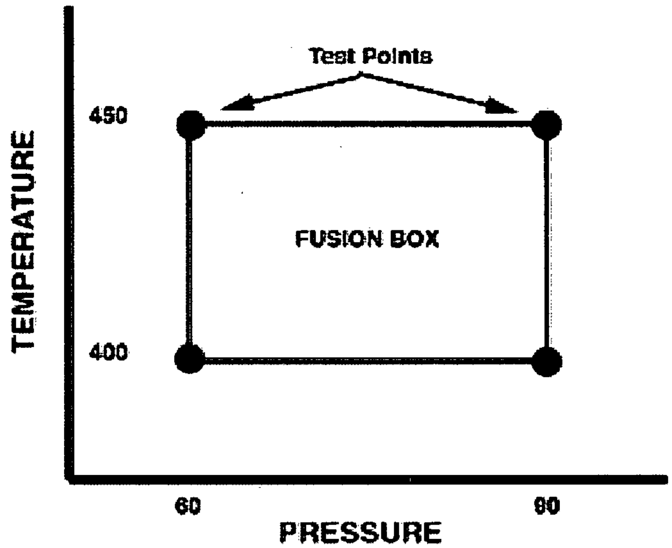
The interfacial pressure is critical to ensure the proper fusion of the melted material when the pipe ends are pressed together. If the pressure is lower than 60 psi the pipe end may not fuse correctly, resulting in "cold fusion." If the pressure is too high, excessive melted material could flow out of the joint creating a poor quality joint.

Pressure Test

Per 49 CFR 192.283 a pressure test is required to verify the strength and quality of the fused joint. One of two methods, sustained pressure test (long term, ASTM D-1598) or quick burst test (short term, ASTM D-1599), can be used.

TR-33 Protocol

Using the Interfacial Pressure and Heater Temperature data, a Fusion Box is created as shown in the figure below.



Any fused joints made using parameters within the "Fusion Box" will have a very high probability of being a properly fused joint. Each corner of the "Fusion Box" is tested using a combination of tests: high speed impact testing, and quick burst testing or sustained pressure testing. If there is a change in essential variables, a new procedure incorporating those variables will necessitate five test coupons (pipe fusion joints) at each of the extremes (20 total coupons)- three for high speed impact testing and two for sustained pressure testing.

Applicability to Callaway

Although PE3408 was used for development of TR-33/2001, Dow Chemical, the constituent supplier for the piping provided for the Callaway ESW project, has provided Callaway with test results for the Dow PE4710 resin confirming acceptability for use with the TR-33/2001 procedure. Information regarding this concern is included in Enclosure 3.

This information from Dow Chemical will be retained in permanent Callaway records.

In addition, and as a performance demonstration of the fusion process and equipment beyond TR33 and PPI requirements, AmerenUE will produce and perform testing on six (6) fusion joint test coupons of 36NPS DR 9.5 material and 4NPS DR 9 material on each model of fusion machine expected to be used in production, as stated in the response to Question 2 below. All data from this performance demonstration will be retained in permanent Callaway records.

Records are produced during qualification of fusion operators on production equipment in accordance with Callaway's fusion qualification program requirements and are retained as permanent records. The instruments used on the production equipment are calibrated under an approved program and the calibration records are also retained as permanent records.

2. 10 CFR 50 Appendix B, Criterion III, Design Control, states, "Where a test program is used to verify the adequacy of a specific design feature in lieu of other verifying or checking processes, it shall include suitable qualifications testing of a prototype unit under the most adverse design conditions." The two procedure qualification methods in Code Case N-755 must demonstrate that they are capable of making acceptable fused joints. The demonstrations must cover pipe sizes and essential variable extremes for the equipment (manufacturer model) that is being used for fusing joints. The reference to PPI report TR-33/2001 does not provide sufficient test data for equipment and procedure-specific qualifications for the essential variable extremes. The performance demonstration should use representative pipe material and pipe sizes (diameter and wall thickness), and the performance demonstration should make sufficient repetitions of fused joints to statistically evaluated equipment and fusion process reliability.

Question/Request:

Provide a discussion describing the performance demonstrations that will be used for equipment and procedure qualifications, and describe the testing that will be used to validate internal soundness supporting equipment and procedure qualifications. Provide the same discussion for each process (butt fusion, electro-fusion. etc,) if more than one process is used for fusing joints.

Response:

AmerenUE has elected to qualify all fusion operators on the standard TR33/2001 procedure using the same size (36 NPS) and thickness (approximately 4 inches) of pipe, same model machines (McElroy and Ritmo), and at the same target values (pressure and temperature) to be used during production. These qualification tests (similar to those specified in 49CFR192.285) simulated the actual production conditions to be employed and therefore serve as performance demonstrations for the process, as well as for the equipment and personnel. From each coupon, two specimens were cut, visually inspected, and hydraulically bend tested to exceed 20% strain at the fusion joint (one test specimen for the interior surface and another for the exterior surface). (The yield point of HDPE typically occurs at approximately 10% strain.) The surfaces of each specimen were visually examined for any evidence of voids, discontinuities, or failure in the joint area.

Sixteen (16) specimens were bend-tested (eight in the fabrication shop and eight in the field), with one test failure. The operator with the one failure in the shop underwent additional training and successfully passed on re-test. In addition, the machine was inspected and adjusted to improve uniformity of heating, and six additional test specimens (for a total of 22) were then produced on the machine – all of which successfully passed the bend-tests. These tests – each pair of which simulates the *single* performance demonstration required by ASME Section IX (QW-510 & QW-302.1) to allow a manufacturer to use a Standard Welding Procedure Specification (QW-100.1) - validate the internal soundness of large diameter heavy wall piping joints made by thermal butt fusion on actual production machines using the standard fusion procedure described in TR33/2001.

As a performance demonstration at the request of the Regulator, AmerenUE will produce six (6) fusion joint test coupons of 36NPS DR 9.5 and six (6) fusion joint test specimens of 4NPS DR 9 material on each model of fusion machine carriage expected to be used in production for the respective size of piping as a performance demonstration. Three (3) of these fusions on each machine will target minimum temperature and interfacial pressure using maximum heater removal times, and three (3) will target maximum temperature and interfacial pressure using minimal heater removal times – to the extent feasible considering production limits, machine capabilities and the limits of the AmerenUE Fusion Procedure Specification.

A minimum of four (4) specimens will be cut from each fusion joint coupon approximately 90 degrees apart and tensile-tested to verify that the fusion joint is stronger than the pipe. Testing will be performed by commercial plastics industry suppliers without a 10 CFR 50 Appendix B quality program, but all testing will be overseen by AmerenUE representatives, and the test records will be retained in permanent Callaway records.

High-speed impact tensile testing for the 4NPS specimens will be performed in accordance with QF-131. This testing will also be performed for the 36NPS specimens if determined feasible and conclusive considering the need – due to tensile machine capability - to test segmented specimens; otherwise, tensile testing for the 36 NPS specimens will be performed with full-section specimens consistent with ASTM Specification D638, "Standard Test Method for Tensile Properties of Plastic," in accordance with the butt fusion procedure qualification requirements of 49CFR192.283 for gas pipelines.

Only the butt thermal fusion process will be used on this project.

Question/Request:

2.(a) QF-223(a) provides one pipe diameter and wall thickness for equipment and procedure qualification testing. The use of a one-size (diameter and wall thickness) pipe to represent all pipe sizes ignores the effect that pipe diameter and wall thickness have on fused joint integrity. The PPI TR-33/2001 report does not provide information to support that a one-size pipe is representative of all pipe sizes. Discuss the demonstration data that supports the representativeness of one pipe size for all pipe size combinations or that supports the range of pipe sizes that will be used. Provide the criteria to be applied to demonstrate fused joint soundness for the range of pipe sizes that will be used.

Response:

There are two options provided for a Fusion Procedure Specification (FPS): use of the Standard FPS based on TR-33, or development and qualification of a new FPS.

Standard FPS Option

The Standard FPS is based on TR-33, which was developed at the request of the United States Department of Transportation to promote greater uniformity in the joining procedures utilized by gas utilities for the butt fusion of polyethylene products. TR-33 has since become the standard industry practice for butt fusion of polyethylene. The conclusion of TR-33/2001, based on the testing of 2 NPS and 8 NPS samples, was that pressure range and temperature range were the only variables essential for successful fusion of a broad range of medium and high density polyethylene piping materials.

TR-33/2006 subsequently expanded this testing to include 12 NPS, 14 NPS, 16 NPS, and 22 NPS samples and concluded that the fusion pressure range and temperature range established in TR-33/2001 are applicable to this expanded range of sizes.

AmerenUE is using this option.

New FPS Option

Use of TR-33 is not mandatory, and every PE pipe producer and pipeline operator retains the option of developing different procedures for its particular products and pipelines. However, to develop a new FPS that deviates from the parameters of TR-33 would require 20 pipe coupons and 13 months of pressure testing. Since the standard procedure developed by TR-33 applies to a broad range of sizes, there would little value added in requalifying for the AmerenUE application.

Callaway Plan

AmerenUE has utilized the Standard FPS for the qualification of all fusion machine operators. As discussed above, this performance qualification /demonstration of the fusion machines and fusion operators also served to demonstrate satisfactory performance of the Standard FPS on 36 NPS DR 9.5 piping.

Also, quick burst test data provided by Dow Chemical (included in Enclosure 3) confirms that joints produced with the TR-33/2001 procedure are stronger than the Dow PE4710 piping base material in sizes up to and including 22 NPS DR 9.

This burst test, coupled with the performance demonstration testing of six (6) fusion joint test coupons of 36NPS DR 9.5 material and 4NPS DR9 material on each model of fusion machine expected to be used in production, exceeds the requirements of 49CFR192.283(a) for butt fusion procedure qualification, and will confirm that the FPS used by AmerenUE is suitable for the sizes and thicknesses of piping that will be used.

QF-223(a) requires pipe coupons made from 8 IPS, DR 11. This size was chosen for ease of manufacturing the high speed tensile specimens and to accommodate the testing machine.

Question/Request:

2.(b) QF-104.1(a) defines essential variables as conditions under which fusing must be performed, and QF-222(a) lists essential variables for procedure and equipment qualifications. The standard fusion procedure specification (QF-221) does not contain all of the essential variables listed in (QF-222) for procedure qualification. Discuss the application of the essential variables listed in QF-222(a) that will be used in the equipment and procedure qualification.

Response:

The essential variables from QF-222 that were not included in QF-221 were (a) pipe material and (d) fusion pressure. In the attached proposed alternative, QF-221(b) has been corrected to include pipe material and QF-222 has been corrected to delete "fusion pressure" which is redundant to "butt fusion interfacial pressure range."

Question/Request:

2.(c) In the submittal, Paragraph 3041 provides criteria for minimum design temperature which may inadvertently be applied to procedure qualifications. The Code Case does not address the effects of lower temperatures on the effectiveness of the fusion process. In response to RAI question 1(b), the licensee stated that the minimum ambient temperature for joint fabrication is 50° F (degrees Fahrenheit) and will apply an environmental enclosure as necessary for temperature control. Since the fusion process is a temperature-dependent process and ambient temperature affects the heater removal to pipe fusion dwell time, the minimum ambient temperature is a variable. Provide the minimum ambient temperature that was used during the performance demonstration for equipment and procedure qualification.

Response:

The 6 NPS and 36 NPS performance qualification/demonstration testing at the fitting fabrication shop was performed indoors at ambient temperatures– approximately 65-75° F. The 6 NPS and 36 NPS performance qualification/ demonstration testing performed at Callaway was performed in a shelter that was open to the atmosphere – with temperatures ranging between 50 and 75° F. Fusing will not be performed in an environment below 50 °F.

Note that AmerenUE has placed this 50 °F lower limit for ambient temperature only as a conservative good practice; neither ASME nor the Plastics Pipe Industry (which often fuses HDPE using the standard procedure at temperatures below freezing) consider ambient temperature to be an important variable for the fusion process.

3. The response to RAI question 3(a) did not address the question of performance-based VT (visual examination) personnel qualifications. Performance-based qualifications are in keeping with NUREG/BR-0303 and NRC's presentation, "NRC Perspective on NDE Performance Demonstration," given July 24, 2006, at the EPRI Performance Demonstration Workshop, Myrtle Beach, SC. The VT examination of HDPE-fused joints is substantially different than VT examinations of metal pipe. Therefore, criteria supplementing the current VT qualification are necessary to measure and verify personnel skill in VT examination of HDPE-fused joints.

Question/Request:

Please supplement the response to RAI question 3(a) that includes criteria for performance-based personnel qualifications.

Response:

All personnel performing Visual Examinations of HDPE pipe fusion joints must be certified VT-1 examination personnel. In addition, they are required to receive the same training as required for the fusion machine operator. This involves a minimum of 24 hours of training, covering the principles of the fusion process and the operation of the fusion equipment. Included is a two-part test addressing theoretical knowledge and machine operation.

These requirements will be supplemented by additional evaluation involving examination of physical samples of visually acceptable and unacceptable HDPE pipe fusion joints. A minimum of five flaw samples will be used for the visual examination procedure demonstration, and five for the personnel demonstration using the visual examination procedure.

Question/Request:

3.(a) In response to RAI questions 3(b) pertaining to inside-surface VT examination, 3(c) pertaining to voids at pipe ends, 3(d) pertaining to voids near the joint, and 4.0 pertaining to in-process testing, the licensee proposed using ultrasonic testing (UT) examinations to verify internal soundness of each fused joint and the adjacent pipe material with the exception of fittings. Currently, there are no UT performance-based criteria that are specific to an HDPE pipe. Provide the performance demonstration criteria for detection of flaws (internal unsoundness), and provide an acceptance criterion statistically establishing detection reliability (an example is the ASME Code, Section XI, Appendix VIII).

Response:

As there are no existing performance-based criteria specific to HDPE piping, a demonstration will be performed to verify that the Time-of-Flight Diffraction (TOFD) procedure utilized will apply available technology for this technique. The demonstration will utilize specimen(s) containing ten flaws of varying shapes, dimensions and relative locations, simulating flaws expected to occur in unacceptable joints.

As discussed in AmerenUE letter ULNRC-05490, the contractor performing the TOFD does not have a 10 CFR 50 Appendix B quality program, but the contractor's examiners will be qualified in accordance with SNT-TC-1A or equivalent, and the inspection records will be retained in permanent Callaway records.

AmerenUE is currently evaluating and refining acceptance criteria based on industry standards (e.g. ASME B31 piping codes). The current acceptance criteria require that any unbonded area in the joint, found as a result of the TOFD, is cause for rejection.

Question/Request:

3.(b) The response to RAI question 2(a) defined accessibility to the inside pipe surface as being within direct VT examination from an open pipe end or fitting end. The definition is ignoring industry experience with remote control VT examination equipment. Remote VT equipment is being used for diameters as small as steam generator tubes. Joints not conducive to UT examinations, such as fittings, will still have to be VT examined from both the inside and outside surfaces. Provide the criteria for VT examinations performed from the inside surfaces regardless of the distance from the pipe end, or provide another means for ensuring internal soundness for fused joints that can not be UT examined.

Response:

All joints that are not visually inspected on the interior beads will be examined using Time-of-flight UT techniques.

4. The NRC staff has not found Code Case N-755 to be acceptable. The reference of Code Case N-755 in the proposed alternative can not be approved at this time. However, a proposed alternative for a site and application-specific request using the applicable parts and modifications provided in the RAI responses may be reviewable.

Question/Request:

Provide a revised proposed alternative that is specific to Callaway's essential service water system repair that does not reference Code Case N-755.

Response:

The revised proposed alternative, i.e., revised Relief Request I3R-10 and its attachment, "Requirements for HDPE Piping for Nuclear Service," is provided in Enclosure 5.

Enclosure 2

Responses to RAI Questions/Requests
from NRC Division of Engineering

OFFICE OF NUCLEAR REACTOR REGULATION

REQUEST FOR ADDITIONAL INFORMATION

RELATED TO ESSENTIAL SERVICE WATER

UNION ELECTRIC COMPANY

CALLAWAY PLANT

DOCKET NO. 50-483

The NRC's Division of Engineering staff has reviewed the licensee's analysis provided in response to its request for additional information (RAI), and has determined that additional RAIs are required based on its review. Please provide a response to the following RAIs to facilitate the continuation of the review by the NRC staff.

In its application dated August 30, 2007 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML072550488), Union Electric Company (AmerenUE) submitted Relief Request (RR) I3R-10 for the replacement of Class 3 buried steel piping in the safety-related essential service water (ESW) system with polyethylene (PE) piping at the Callaway Plant, Unit 1 (Callaway). AmerenUE stated that the construction code of record for buried Class 3 piping is the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, subsection ND, 1974 Edition through Summer 1975 Addenda. As the construction code and later editions and addenda do not provide rules for the design, fabrication, installation, examination, and testing of piping constructed using PE material, AmerenUE requests the approval of RR I3R-10 for the use of PE piping. AmerenUE proposed to use the provisions of the ASME Code Case N-755 for the ESW piping replacement effort. Since the relief request did not contain detailed technical documentation, the NRC staff requested detailed technical information that was captured in six questions in its initial RAI on February 29, 2008. AmerenUE responded to the NRC RAIs by ULNRC~05490 dated April 17, 2008 (ADAMS Accession No. ML081190648), which included three enclosures (Reference 1).

Based on our review of the information in Reference 1, the following additional information is requested. Callaway is the first licensee that requested to utilize PE 4710 material piping in a safety-related ASME Class 3 application, and is the first to use temperatures higher than 100 °F (degrees Fahrenheit), pressures higher than 115 psig (pounds per square inch gauge), and diameters larger than 12.75 inches.

1. AmerenUE is requested to supplement the relief request to address specific aspects that prompted the NRC staff to not endorse ASME Code Case N-755.

NRC's review of the methodology utilized in the relief request is specific for the Callaway application only. The industry is engaged in an extensive ongoing testing program to establish the full range of properties, fatigue data, stress intensification factors, long-term creep rupture data, and slow crack-growth characteristics for the specific grade of PE material (PE 4710) to be utilized in the requested Callaway application. The current test data that support a fatigue-allowable of 1100 pounds per square inch (psi) for PE 3408 material data is very limited and does not meet the provisions in Section III of the ASME Code for establishing fatigue curves (Electric Power Research Institute (EPRI) Report 1013549). More investigations are needed to confirm the short-duration (30 days) stress allowables, and applicable design factors. Furthermore, techniques to ensure the structural integrity of fusion joints are still evolving. Finally, there is currently no domestic performance or operating experience history regarding PE piping's use in nuclear safety-related applications.

Question/Request:

In light of these considerations and in conjunction with this request for alternative, AmerenUE should include whether it will formally commit to:

(a) Prior to submitting Callaway's fourth 10-year interval in-service inspection plan, Callaway will submit information obtained from the above referenced industry testing program to the NRC. If the information supports operation using PE 4710 for the remainder of plant life, this information will be submitted to the NRC for information only.

(b) If the information does not support operation using PE 4710 for the remainder of plant life, this information will be submitted to the NRC as part of a subsequent request for alternative for the fourth 10-year interval.

Response:

AmerenUE will evaluate future investigations performed by the industry to confirm the short-duration (30-day) stress allowables and applicable design factors applied at Callaway for the PE4710 piping. AmerenUE will also evaluate future evolution of the fusion technique to validate structural integrity of the installed fusion joints. The results will be submitted to the NRC prior to submittal of Callaway's fourth 10-year interval in-service inspection plan, and will include, if necessary, a fourth-interval alternative request.

2. In Enclosure 1 (page 18 of 20), Attachment 2, Design Paragraph 3016, and in Enclosure 3 (page 4 of 152), Section 4.2.2 of Reference 1, AmerenUE states that the Miner's Rule in accordance with ISO 13760 will be used to account for operation for 30 days at (plant) post-accident conditions and normal operating conditions for the balance of the 40-year design life. However, there was no such evaluation included in Enclosure 3, Preliminary Stress Calculation 2007-16760.

Question/Request:

Provide the evaluation based on the Miner's Rule.

Response:

The use of Miner's Rule is documented in the design minimum wall thickness calculation, i.e., Callaway calculation No. 2007-13241. This calculation is provided in Enclosure 4. (Note: The calculation in Enclosure 4 is not finalized but will be available for inspection after finalization.)

3. In response to the staff's RAI question 6 (Enclosure 1, page 13 of 20, Reference 1), you stated that any sections with flaws exceeding 10 percent of wall thickness in 4-inch piping or flaws exceeding 7 percent of wall thickness in 36-inch piping shall be cut out and replaced. The response further stated that flaws below the above-stated limits will be left as-is or smoothly blended. Some degree of conservatism needs to be maintained in order to account for the uncertainties in the PE material properties. The ESW supply, return, and backwash lines, when replaced with PE material, will be subjected to relatively high temperatures (175 °F) and/or pressures (for a 36-inch supply line, 95 °F/190 psig; for a 36-inch return line, 175 °F/45 psig; and for a 4-inch backwash line, 95 °F/180 psig). In the minimum required wall thickness (tmin) calculations, the fabricated thickness (tactual) without accounting for the reduced wall thickness due to flaws was utilized, and the margins left are practically insignificant as shown in Section 8.1.1 of Enclosure 3, page 141 of 152 of Reference 1. (For a supply line, tmin = 3.82 inches versus tactual = 3.85 inches; for a backwash line, tmin = 0.46 inches versus tactual = 0.5 inches.)

Question/Request:

3.(a) The NRC requests your reassessment of the minimum required wall thickness accounting for flaw depth in actual thickness. Please confirm that the remaining thickness (93 percent thickness (%t) for 36-inch pipes and 90 %t for 4-inch pipes in Section 7.1, Pressure Design of HDPE Pipes, of Enclosure 3, Reference 1) exceeds the minimum required ASME Code thickness.

Response:

In response to the staff's concern, the following revised procedure for addressing damage to polyethylene piping under the scope of this project is provided:

(1) For 4-inch piping, any section with a flaw exceeding 10% of the wall thickness shall be cut out and replaced.

(2) For 36-inch piping, any section with a flaw exceeding 7% of the wall thickness shall be cut out and replaced.

(3) Wherever a flaw will result in a remaining wall thickness less than the required as-fabricated minimum wall thickness per ASTM F714, the affected section of piping shall be cut out and replaced or the stresses in the affected section shall be re-evaluated and determined to be acceptable considering the remaining wall thickness.

(4) Any section of piping with a flaw not exceeding 5% of the wall thickness and not resulting in a remaining wall thickness less than the required as-fabricated minimum wall thickness per ASTM F714 may be left as-is.

(5) All other flaws shall be removed by blending as follows:

(a) The depression after flaw elimination is blended uniformly into the surrounding surface with a maximum taper not to exceed 3:1 (ratio of width to height).

(b) After flaw elimination, the area will be examined by visual examination to ensure that the flaw has been removed.

(c) If the elimination of the flaw reduces the thickness of the section below the minimum required design thickness, the section of piping containing the flaw shall be cut out and replaced.

Question/Request:

3.(b) The NRC also requests you to confirm that the remaining wall thickness (93 %t for 36-inch pipes and 90 %t for 4-inch pipes) was used, rather than the fabricated wall thickness, in all of the structural integrity calculations (Reference 1, Section 7.3, Soil and Surcharge Analysis; Section 7.5, Longitudinal Stress Analysis; Section 7.6, Thermal Expansion Stress Calculations; Section 7.7, Seismic Stress Calculations; and Section 7.8, Pipe Systems Finite Element Analysis) to establish the acceptability.

Response:

The final analysis will use the required as-fabricated minimum wall thickness per ASTM F714 in all structural integrity calculations. As stated in the response to RAI 3(a) above, wherever a flaw will result in a remaining wall thickness less than the required as-fabricated minimum wall thickness per ASTM F714, the affected piping section shall be cut out and replaced or the stresses in the affected section shall be reevaluated and determined to be acceptable considering the remaining wall thickness.

4. For Combined Seismic Induced Stresses [Seismic Wave Passage (equivalent thermal) and Building Seismic Anchor Motion], Enclosure 3, Reference 1: Section 7.7.2 (page 64 of 152, Return Lines); Section 7.7.3 (pages 70 of 152 and 74 of 152), the evaluations were based on a stress intensification factor, $i = 1.0$, for a straight pipe only. There is no sketch of the pipe layout provided to show the locations of mitered elbows, flange connections, interfaces with steel pipe, and buildings, and important joint numbers.

Question/Request:

4.(a) Provide a simple schematic of piping layout showing at least the major details. Include orientation of N-S, E-W, and vertical directions along with Global X, Y, and Z coordinate axes.

Response:

A simple schematic of the piping layout (i.e., drawing C-U206) is provided on page 14 of this enclosure.

Question/Request:

4.(b) Include a stress evaluation at a miter-bend location with a stress intensification factor, i = 2.0.

Response:

Based on the results of the preliminary analysis, the locations of peak stress occurred in the straight pipe sections, even when a stress intensification factor of i = 2.0 was considered for mitered elbows. The final analysis will summarize the peak stress value in straight pipe and the peak stress in mitered elbows. A stress intensification factor of i = 2.0 will be used for mitered elbow locations.

4.(c) In the stress evaluations, the resultant moment was computed using two moment components (about vertical and transverse axes) only. Piping design rules specify the use of all three moment components including torsional moment in resultant moment computation. Please explain the rationale for your deviation.

Response:

The final analysis will compute resultant moments using all three moment components. This change is not expected to have a significant impact on the analysis results.

5. For Pipe Systems Finite Element Analyses, Enclosure 3, Reference 1, Section 7.8.1 (pages 104 of 152 and 105 of 152, SAP2000 Output, Return Lines), the evaluations were based on a stress intensification factor, i = 2.0, for a critical miter-bend location.

Question/Request:

5.(a) Secondary or Thermal expansion stress evaluation should be based on range of all thermal modes or load cases. Based on page 75 of 152:

Load Case 1: Twater - Tground = 175-70 = +105 °F; and Load Case 2:

Twater - Tground = 32-55 = -23 °F and not +60 °F as was used in the evaluation.

Since Load Case 2 has a negative temperature difference, the moment range between Load Case 1 and Load Case 2 will be higher than due to Load Case 1 or Load Case 2 alone. Given that your evaluation does not account for thermal expansion stress based on maximum range of moments, you are requested to explain the rationale for your thermal analysis or provide a re-evaluation consistent with maximum bounding thermal moment range. Typical piping stress analysis programs compute moment ranges for load cases, apply the appropriate stress intensification, and automatically compute intensified stresses at every node point in accordance with applicable ASME Section III Code edition. Are you doing stress computations manually using moments from SAP2000, because the SAP2000 program version V7.40 utilized for PE piping analysis does not have these features built-in?

Response:

If the alternative thermal expansion and contraction evaluation is performed in the final analysis, the range of moments for the expansion and contraction cases will be evaluated instead of evaluating the expansion and contraction cases individually.

For the fully constrained thermal expansion and contraction evaluations, the calculated thermal stresses will be based on the temperature differential between the pipe operating temperature and the soil temperature. This approach is supported by EPRI document 1013549, "Nondestructive Evaluation: Seismic Design Criteria for Polyethylene Pipe Replacement Code Case," and EPRI document 1013549, "Design and Qualification of High-Density Polyethylene for ASME Safety Class 3 Piping Systems."

Stress computations are performed manually in Mathcad using the output from SAP2000 because SAP2000 does not have built-in features for PE piping analysis.

Question/Request:

5.(b) In the stress evaluations, the resultant moment was computed using two moment components (about vertical and transverse axes) only. NRC requests a re-evaluation using all three moment components including torsional moment in resultant moment computation (similar to item 4.(c) above of this RAI).

Response:

The final analysis will compute resultant moments using all three moment components. This change is not expected to have a significant impact on the analysis results.

6. For Pipe Systems Finite Element Analyses, Enclosure 3, Reference 1, Section 7.8.2 (pages 139 of 152 and 140 of 152, SAP2000 Output, Backwash Lines), the evaluations were based on a stress intensification factor, i = 2.0, for a miter-bend location.

Question/Request:

6.(a) Secondary or Thermal expansion stress evaluation should be based on a range of all thermal modes or load cases. Based on page 100 of 152, Load Case 1: Twater - Tground = 95-70 = +25 °F; Load Case 2: Twater - Tground = 32-55 = -23 °F and not +20 °F as was used in the evaluation. Since Load Case 2 has a negative temperature difference, the moment range between Load Case 1 and Load Case 2 will be higher than due to Load Case 1 or Load Case 2 alone. An explanation for this discrepancy is requested, or a re-evaluation of thermal expansion stress based on maximum range of moments is required.

Response:

As stated in the response to RAI 5.(a), if the alternative thermal expansion and contraction evaluation is performed in the final analysis, the range of moments for the expansion and contraction cases will be evaluated instead of evaluating the expansion and contraction cases individually.

For the fully constrained thermal expansion and contraction evaluations, the calculated thermal stresses will be based on the temperature differential between the pipe operating temperature and the soil temperature. This approach is supported by EPRI document 1013549, "Nondestructive Evaluation: Seismic Design Criteria for Polyethylene Pipe Replacement Code Case," and EPRI document 1013549, "Design and Qualification of High-Density Polyethylene for ASME Safety Class 3 Piping Systems."

Question/Request:

6.(b) In the stress evaluations, the resultant moment was computed using two moment components (about vertical & transverse axes) only. NRC requests a re-evaluation using all three moment components including torsional moment in resultant moment computation.

Response:

The final analysis will compute resultant moments using all three moment components. This change is not expected to have a significant impact on the analysis results.

7. For SAP2000 Input/Output, Enclosure 3, Reference 1 (page 10 of 24 of Attachment 10.4; page 10 of 19 of Attachment 10.5; page 13 of 37 of Attachment 10.6; and page 13 of 37 of Attachment 10.7), the value of 8.980E-05 kips per cubic inch used for weight per unit volume for PE material under material property data does not agree with the value of 0.959 grams per cubic centimeter (which corresponds to 3.465E-05 kips per cubic inch) given on page 7 of 152.

Question/Request:

Explain the discrepancy in the weight per unit volume for PE material and evaluate the impact, if any, on the results.

Response:

The weight per unit volume value input into SAP2000 for PE pipe is a value that is representative of both the PE pipe and the water inside the pipe. The value is equivalent to the total weight of PE and water per unit length of pipe divided by the area of pipe material. As shown on page 10 of 24 of Attachment 10.4 and page 10 of 19 of Attachment 10.5, this value equates to 9.290E-05 kips per cubic inch for the 36" pipe. As shown on page 13 of 37 of Attachment 10.6 and page 13 of 37 of Attachment 10.7, this value equates to 8.980E-05 kips per cubic inch for the 4" pipe.

8. For Allowable Stress for Circumferential Compressive Stress in the sidewalls (Section 7.3, page 33 of 152 and Section 6.2.1, page 15 of 152), the NRC finds inappropriate the use of a constant allowable of 1000 psi (without any temperature dependence) for compression of sidewalls in PE piping.

Question/Request:

A re-evaluation is required using an allowable stress corresponding to the temperature to which the piping is subjected. For supply and backwash lines, it should be 695 psi at 95 °F, and for return lines it should be 340 psi at 175 °F in lieu of a constant 1000 psi.

Response:

The final analysis will use temperature-dependent allowable stress values for evaluation of circumferential compressive stress in the sidewalls as requested. A review of the calculated stresses in the preliminary analysis shows that the use of temperature-dependent allowable stress values in lieu of a constant allowable stress value of 1000 psi will not change the conclusion that the calculated stresses are less than the allowable stresses.

9. For Flotation Analysis (Section 7.4, page 44 of 152), i.e., the weight of water (Ww) displaced by the pipe, the per-unit length (upward buoyant force) should be based on the outside diameter of the pipe. The calculations in Section 7.4 were based on the inside diameter of the pipe.

Question/Request:

Please re-evaluate the calculations based on outside diameter of supply, return, and backwash lines.

Response:

The final analysis will perform flotation analysis based on the outside diameter of the pipe. This change is not expected to change the results of the flotation analysis.

10. For Longitudinal Stress Analysis (pages 46 of 152 through 52 of 152 in Sections 7.5.1, 7.5.2, and 7.5.3, Reference 1), the evaluations were based on primary stress indices of $B_1 = 0.5$ and $B_2 = 1.0$ for a straight pipe only. For mitered elbows with a diameter ratio of DR = 9, $B_1 = 0.69$ and $B_2 = 1.64$; and with a diameter ratio of DR = 9.35, $B_1 = 0.69$ and $B_2 = 1.69$.

Question/Request:

10.(a) Include stress evaluation at a critical miter-bend location also with applicable primary stress indices.

Response:

Based on the results of the preliminary analysis, the locations of peak longitudinal stress occurred in the straight pipe sections, even when the mitered elbow primary stress indices were considered. The final analysis will summarize the peak longitudinal stress value in straight pipe and the peak longitudinal stress in mitered elbows. The mitered elbow primary stress indices will be used for mitered elbow locations.

Question/Request:

10.(b) In the stress evaluations, the resultant moment was computed using two moment components (about vertical and transverse axes) only. NRC requires a re-evaluation using all three moment components including torsional moment in resultant moment computation.

Response:

The final analysis will compute resultant moments using all three moment components. This change is not expected to have a significant impact on the analysis results.

11.

Question/Request:

11.(a) For Stress Allowable at 176 °F (Enclosure 3, Attachment 10.3, page 2 of 2, Reference 1), is 340 psi considered as the allowable with DF = 0.5 for 2.5 years of continuous operation or for 30 days of continuous operation? Please provide clarification. Also, note that DF > 0.5 which corresponds to a factor of safety of less than 2 is not acceptable to the NRC.

Response:

As documented in the design minimum wall thickness calculation, which is included as Enclosure 4, the allowable stress value for 30 days of continuous operation at 175 °F is conservatively considered to be the same as the allowable stress value for 2.5 years of continuous operation at 176 °F. Also note that as the ESW operating temperature is expected to drop significantly within the first several days post-accident, the assumption that the peak post-accident operating temperature will occur continuously for 30 days is conservative.

With regard to the design factor, Ameren intends to utilize a design factor of 0.56 in lieu of 0.5. The justification for this approach is provided in Enclosure 6.

Question/Request:

11.(b) Are the additional loads from the buried piping side included in the design of interface anchors at the control building, UHS Control Tower, ESW pump house, ESW Yard Vaults, and others, if any? Please provide a summary of anchor loads.

Response:

The anchors attach to the metallic piping, as close as practically possible to the flanged interfaces between the HDPE piping and metallic piping. The combined anchor design loads are determined in the above ground piping analysis calculations using traditional piping stress analysis software. In order to obtain loads from the HDPE side of the anchors, the computer models used in the above ground piping analysis calculations include the metallic piping on the HDPE side of the anchors up to the interface with the HDPE piping. The models also include a lumped mass at the end of the metallic piping that bounds the total weight of the HDPE transition flange, metallic flange and metallic back-up ring. The loads acting on the HDPE side and the loads acting on the metallic side of the anchor are calculated by the piping stress analysis software. A summary of preliminary combined anchor loads is provided on pages 15 and 16 of this enclosure.

Question/Request:

11.(c) For Ring Deflection Equation (page 15 of 152, Enclosure 3, Reference 1), clarify that Ω, Ωmax are non-dimensional ring deflections, that is, a ratio of ring deflection to diameter and not ring deflection values. Since the units for vertical soil pressure due to earth load (PE) and pressure due to surcharge load (PL) seismic anchor motion (SAM) are in psf (pounds per square foot) and the units for E_{pipe} and E' are in psi, a 1/144 factor is required.

Response:

Within the preliminary analysis, the calculated and allowable ring deflections as percentages of the diameter are multiplied by the diameter to provide deflections in terms of inches. This has no impact on the results of the ring deflection evaluation. The preliminary evaluation is performed using Mathcad software. Mathcad software automatically performs unit conversions. Therefore, the inclusion of the 1/144 factor is not required.

Question/Request:

11.(d) For Flotation (page 16 of 152, Enclosure 3, Reference 1), since the units for PE are in psf, and the units for D are in inches, a 1/12 factor for the term (P_E.D) is required.

Response:

The preliminary evaluation is performed using Mathcad software. Mathcad software automatically performs unit conversions. Therefore, the inclusion of the 1/12 factor is not required.

Question/Request:

11.(e) Concerning Enclosure 2 of Reference 1, please provide clarification for the terms CRS and HBD (or HDB?).

Response:

The term "HBD" in Enclosure 2 of Reference 1 is a typo. It should be "HDB" which stands for Hydrostatic Design Basis. As defined in ASTM D-2837, *hydrostatic design basis (HDB)* — one of a series of established stress values for a compound. It is obtained by categorizing the long-term hydrostatic strength (LTHS) in accordance with Table 1.

TABLE 1 Hydrostatic Design Basis Categories

NOTE 1—The LTHS is determined to the nearest 10 psi. Rounding procedures in Practice E 29 should be followed.

Range of Calculated LTHS Values		Hydrostatic Design Basis	
psi	(MPa)	psi	(MPa)
190 to < 240	(1.31 to < 1.65)	200	(1.38)
240 to < 300	(1.65 to < 2.07)	250	(1.72)
300 to < 380	(2.07 to < 2.62)	315	(2.17)
380 to < 480	(2.62 to < 3.31)	400	(2.76)
480 to < 600	(3.31 to < 4.14)	500	(3.45)
600 to < 760	(4.14 to < 5.24)	630	(4.34)
760 to < 960	(5.24 to < 6.62)	800	(5.52)
960 to <1200	(6.62 to < 8.27)	1000	(6.89)
1200 to <1530	(8.27 to <10.55)	1250	(8.62)
1530 to <1920	(10.55 to <13.24)	1600	(11.03)
1920 to <2400	(13.24 to <16.55)	2000	(13.79)
2400 to <3020	(16.55 to <20.82)	2500	(17.24)
3020 to <3830	(20.82 to <26.41)	3150	(21.72)
3830 to <4800	(26.41 to <33.09)	4000	(27.58)
4800 to <6040	(33.09 to <41.62)	5000	(34.47)
6040 to <6910	(41.62 to <48.92)	6300	(43.41)
6910 to <7920	(48.92 to <54.62)	7100	(48.92)

HDB = 1600 psi for PE 3408 & PE 4710

As defined in ASTM D2837, *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 pipe will not occur. This stress is circumferential when internal hydrostatic water pressure is applied. The HDS is the product of HDB and the design factor (DF).

HDS = HDB X DF

The term "CRS" stands for Categorized Required Strength. As defined in Plastics Pipe Institute (PPI) document TR-3, *Categorized Required Strength CRS (Θ, t)* is the Categorized Required Strength value of σ_{lpl} determined and categorized for the selected temperature (θ) and required time (t) in accordance with the ISO 9080 using 3 or 4 coefficient stress rupture/time equation.

12. Enclosure 3, page 11 of 152, Reference 1, states that preliminary finite element analyses studies indicated that lower soil spring stiffness gave higher thermal stresses in buried HDPE piping and the inverse for the combined seismic wave passage and SAM controlled by SAM.

Question/Request:

Provide a simple summary table of the study runs, including a discussion of the spacing utilized for the soil springs.

Response:

As discussed in EPRI document 1013549, "Design and Qualification of High-Density Polyethylene for ASME Safety Class 3 Piping Systems," most of the movements in buried piping are absorbed with a short distance (i.e. the influence length) of changes in direction. EPRI document 1013549 recommends that springs be spaced at distance of two pipe diameters (2D) within the influence length and at a distance of 10D beyond the influence length. Within the SAP2000 analysis model, springs near mitered elbows were spaced at a distance of approximately 1D. All other springs (i.e. between large spans) were spaced at a distance between approximately 3D and approximately 5D. As the greater the number of modeled springs, the more accurately the results will reflect the behavior of the buried pipe under the load conditions. This spacing is conservative when compared to the EPRI recommendations.

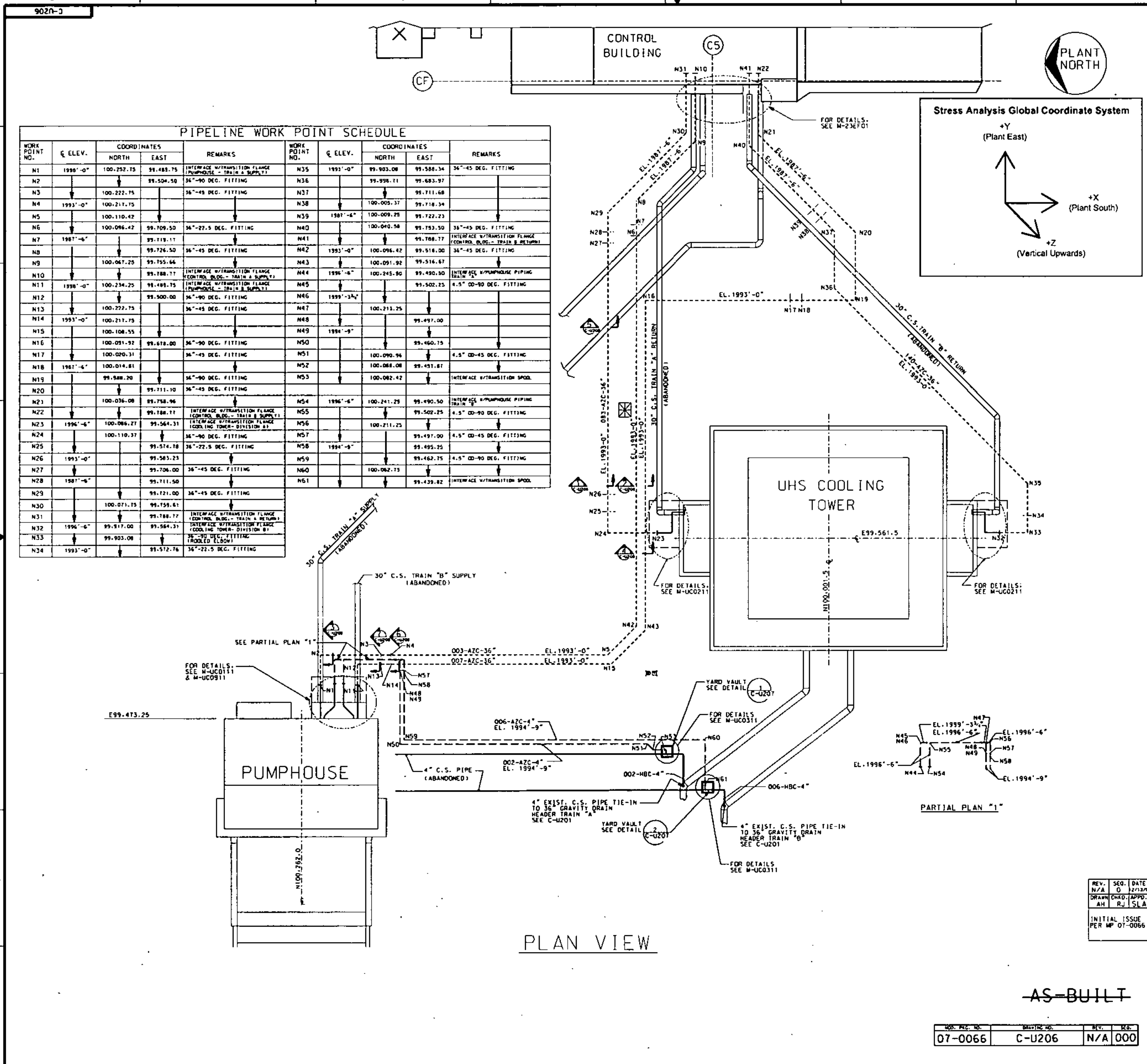
Summary tables of the study runs are provided on pages 17 and 18 of this enclosure.

C-U206

PIPELINE WORK POINT SCHEDULE

WORK POINT NO.	℄ ELEV.	COORDINATES NORTH	COORDINATES EAST	REMARKS
N1	1996'-0"	100,252.75	99,489.75	INTERFACE W/TRANSITION FLANGE (PUMPHOUSE - TRAIN A SUPPLY)
N2			99,504.50	36"-90 DEG. FITTING
N3		100,222.75		36"-45 DEG. FITTING
N4	1993'-0"	100,217.75		
N5		100,110.42		
N6		100,096.42	99,709.50	36"-22.5 DEG. FITTING
N7	1987'-6"		99,719.17	
N8			99,726.50	36"-45 DEG. FITTING
N9		100,067.25	99,755.66	
N10			99,788.77	INTERFACE W/TRANSITION FLANGE (CONTROL BLDG.- TRAIN A SUPPLY)
N11	1996'-0"	100,234.25	99,489.75	INTERFACE W/TRANSITION FLANGE (PUMPHOUSE - TRAIN B SUPPLY)
N12			99,500.00	36"-90 DEG. FITTING
N13		100,222.75		36"-45 DEG. FITTING
N14	1993'-0"	100,217.75		
N15		100,108.55		
N16		100,051.92	99,678.00	36"-90 DEG. FITTING
N17		100,020.31		36"-45 DEG. FITTING
N18	1987'-6"	100,014.81		
N19		99,988.20		36"-90 DEG. FITTING
N20			99,711.10	36"-45 DEG. FITTING
N21		100,036.08	99,758.96	
N22			99,788.77	INTERFACE W/TRANSITION FLANGE (CONTROL BLDG.- TRAIN B SUPPLY)
N23	1996'-6"	100,086.27	99,564.31	INTERFACE W/TRANSITION FLANGE (COOLING TOWER- DIVISION A)
N24		100,110.37		36"-90 DEG. FITTING
N25			99,574.78	36"-22.5 DEG. FITTING
N26	1993'-0"		99,583.23	
N27			99,706.00	36"-45 DEG. FITTING
N28	1987'-6"		99,711.50	
N29			99,721.00	36"-45 DEG. FITTING
N30		100,071.75	99,759.61	
N31			99,788.77	INTERFACE W/TRANSITION FLANGE (CONTROL BLDG.- TRAIN A RETURN)
N32	1996'-6"	99,917.00	99,564.31	INTERFACE W/TRANSITION FLANGE (COOLING TOWER- DIVISION B)
N33		99,903.08		36"-90 DEG. FITTING (ROLLED ELBOW)
N34	1993'-0"		99,572.76	36"-22.5 DEG. FITTING

WORK POINT NO.	℄ ELEV.	COORDINATES NORTH	COORDINATES EAST	REMARKS
N35	1993'-0"	99,903.08	99,588.34	36"-45 DEG. FITTING
N36		99,998.71	99,683.97	
N37			99,711.68	
N38		100,005.37	99,718.34	
N39	1987'-6"	100,009.25	99,722.23	
N40		100,040.58	99,753.50	36"-45 DEG. FITTING
N41			99,788.77	INTERFACE W/TRANSITION FLANGE (CONTROL BLDG.- TRAIN B RETURN)
N42	1993'-0"	100,096.42	99,518.00	36"-45 DEG. FITTING
N43		100,091.92	99,516.67	
N44	1996'-6"	100,245.80	99,490.50	INTERFACE W/PUMPHOUSE PIPING TRAIN "A"
N45			99,502.25	4.5" OD-90 DEG. FITTING
N46	1999'-3¾"			
N47		100,211.25		
N48			99,497.00	
N49	1994'-9"			
N50			99,460.75	
N51		100,090.96		4.5" OD-45 DEG. FITTING
N52		100,088.08	99,451.87	
N53		100,082.42		INTERFACE W/TRANSITION SPOOL
N54	1996'-6"	100,241.29	99,490.50	INTERFACE W/PUMPHOUSE PIPING TRAIN "B"
N55			99,502.25	4.5" OD-90 DEG. FITTING
N56		100,211.25		
N57			99,497.00	4.5" OD-45 DEG. FITTING
N58	1994'-9"		99,495.25	
N59			99,462.75	4.5" OD-90 DEG. FITTING
N60		100,062.75		
N61			99,439.82	INTERFACE W/TRANSITION SPOOL



PLAN VIEW

NOTES

1. FOR DETAILS OF THE ABANDONED BURIED ESW PIPING AND THE 36" GRAVITY DRAIN LINES. SEE DRAWINGS C-U201. C-U202 & C-U204.
2. WHERE NOT PROTECTED BY CONCRETE. THE TOP OF THE ESW PIPING SHALL BE BURIED UNDER A MINIMUM OF 4'-6" OF SOIL FOR TORNADO MISSILE AND FREEZE PROTECTION.
3. THE PIPING HAS BEEN DESIGNED FOR STANDARD AASHTO TRUCK (HS20-44) LOADING AT THE DEPTH OF INSTALLATION INDICATED IN NOTE 2. IF HEAVY LOADS. SUCH AS TRANSFORMERS OR STEAM GENERATORS. ARE TO TRAVEL OVER THIS PIPING. IT MUST BE EVALUATED FOR THOSE SPECIFIC HEAVY LOADING CONFIGURATIONS IF THEY HAVE THE POTENTIAL TO EXCEED STANDARD TRUCK LOADING AT THIS DEPTH.
4. ESW UNDERGROUND HDPE PIPING IS TO BE INSTALLED IN ACCORDANCE WITH SPECIFICATION S-1080.
5. THE BURIED PIPING WORKING POINT COORDINATEDS FOR EAST & NORTH ARE WITHIN +/- 12" FOR 30" DIA. PIPE AND +/- 6" FOR 4" DIA. PIPE.

REFERENCE DRAWINGS

C-U207	YARD VAULTS SECTIONS & DETAILS
C-U208	UNDERGROUND PIPING TRENCH DETAILS
C-UC309	ESW PUMPHOUSE VAULTS PLANS & SECTIONS
C-UC516	UHS COOLING TOWER PENETRATION ROOMS - PLANS

INITIAL ISSUE PER MP 07-0066

~~AS-BUILT~~

07-0066 | C-U206 | N/A | 000

E.S.W.S. REPLACEMENT YARD PIPING PLAN

CALLAWAY PLANT

UNION ELECTRIC COMPANY ST. LOUIS, MO.

C-U206

Preliminary HDPE to Metallic Piping Interface Anchor Combined Loads

ESW Pumphouse 36" HDPE to 30" Metallic Piping Anchors

Anchor EF11-A003 (Train 'A' Supply)

Service Level	Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (ft-lbs)	My (ft-lbs)	Mz (ft-lbs)
Normal (A)	0 / -601	0 / -9360	0 / -2893	0 / -27823	5706 / 0	0 / -3026
Upset (B)	2022 / -2809	0 / -10803	1706 / -5573	0 / -36458	14371 / -7212	8027 / -13696
Faulted (D)	3920 / -4707	0 / -11648	3869 / -7737	0 / -43279	21972 / -14812	17380 / -23049

Anchor EF11-A004 (Train 'B' Supply)

Service Level	Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (ft-lbs)	My (ft-lbs)	Mz (ft-lbs)
Normal (A)	601 / 0	0 / -9360	0 / -2893	0 / -27823	0 / -5706	0 / -3026
Upset (B)	2817 / -2030	0 / -10957	1736 / -5603	0 / -36790	7240 / -14400	13720 / -8051
Faulted (D)	4722 / -3935	0 / -11877	3913 / -7781	0 / -43730	14865 / -22025	23095 / -17426

Control Building 36" HDPE to 30" Metallic Piping Anchors

Anchor EF01-A001 (Train 'A' Supply)

Service Level	Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (ft-lbs)	My (ft-lbs)	Mz (ft-lbs)
Normal (A)	0 / -5300	0 / -12526	3424 / 0	14713 / 0	0 / -13133	4128 / -478
Upset (B)	0 / -6477	0 / -14659	4651 / 0	18503 / 0	1255 / -14857	5073 / -1368
Faulted (D)	695 / -7237	0 / -15933	5357 / -647	20564 / 0	2207 / -15808	5426 / -1722

Anchor EF01-A002 (Train 'B' Supply)

Service Level	Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (ft-lbs)	My (ft-lbs)	Mz (ft-lbs)
Normal (A)	1896 /-2594	0 / -13459	4016 / 0	16578 / 0	5939 / -7261	10486 / -3852
Upset (B)	4453 / -5151	0 / -20592	6678 / -880	30837 / -1027	9987 / -11310	21543 / -14909
Faulted (D)	5252 / -5950	0 / -22506	7313 / -1515	34513 / -4702	11479 / -12801	24251 / -17617

Anchor EF01-A003 (Train 'A' Return)

Service Level	Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (ft-lbs)	My (ft-lbs)	Mz (ft-lbs)
Normal (A)	2158 / -4468	0 / -13851	3651 / -1749	11874 / 0	5101 / -9220	3734 / 0
Upset (B)	3836 / -6146	0 / -17408	4836 / -2934	18589 / -3855	8150 / -12269	6812 / -1776
Faulted (D)	9558 / -6691	7944 / -18635	5122 / -7443	21157 / -13443	20487 / -13377	9589 / -2712

Anchor EF01-A004 (Train 'B' Return)

Service Level	Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (ft-lbs)	My (ft-lbs)	Mz (ft-lbs)
Normal (A)	441 / 0	0 / -7760	852 / 0	6179 / 0	2973 / 0	0 / -1408
Upset (B)	5819 / -5163	0 / -9638	1423 / 0	9156 / 0	8766 / -3648	29646 / -31892
Faulted (D)	4586 / -3804	10566 / -10167	1452 / -7934	10324 / -20224	10805 / -4160	19569 / -22463

Preliminary HDPE to Metallic Piping Interface Anchor Combined Loads (Continued)

UHS Cooling Tower 36" HDPE to 30" Metallic Piping Anchors

Anchor EF11-A001 (Train 'A' Return)

Service Level	Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (ft-lbs)	My (ft-lbs)	Mz (ft-lbs)
Normal (A)	4680 / -1242	0 / -10095	819 / -4492	8554 / -17783	0 / -3195	23770 / 0
Upset (B)	6082 / -2644	0 / -11810	3171 / -6844	19886 / -29115	5552 / - 10108	30166 / 0
Faulted (D)	6539 / -3100	0 / -12482	4155 / -7828	24388 / -33617	8453 / -13009	32396 / 0

Anchor EF11-A002 (Train 'B' Return)

Service Level	Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (ft-lbs)	My (ft-lbs)	Mz (ft-lbs)
Normal (A)	4680 / -1242	0 / -10095	819 / -4492	8554 / -17783	0 / -3195	23770 / 0
Upset (B)	6082 / -2644	0 / -11810	3171 / -6844	19886 / -29115	5552 / - 10108	30166 / 0
Faulted (D)	6539 / -3100	0 / -12482	4155 / -7828	24388 / -33617	8453 / -13009	32396 / 0

ESW Pumphouse 4" HDPE to 4" Metallic Piping Anchors

Anchor EF11-A005 (Train 'A' Backwash)

Service Level	Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (ft-lbs)	My (ft-lbs)	Mz (ft-lbs)
Normal (A)	30 / -35	0 / -300	104 / -116	0 / -598	153 / -96	168 / 0
Upset (B)	188 / -193	0 / -473	478 / -490	386 / -1461	683 / -626	379 / -103
Faulted (D)	229 / -234	0 / -518	584 / -596	606 / -1682	824 / -767	441 / -164

Anchor EF11-A006 (Train 'B' Backwash)

Service Level	Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (ft-lbs)	My (ft-lbs)	Mz (ft-lbs)
Normal (A)	47 / -9	0 / -274	141 / -58	0 / -634	5 / -208	0 / -232
Upset (B)	181 / -143	0 / -461	561 / -478	647 / -1699	505 / -708	87 / -489
Faulted (D)	238 / -200	0 / -537	711 / -629	1040 / -2091	722 / -925	215 / -617

ESW Yard Vault 4" HDPE to 4" Metallic Piping Anchors

Anchor EF11-A007 (Train 'A' Backwash)

Service Level	Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (ft-lbs)	My (ft-lbs)	Mz (ft-lbs)
Normal (A)	0 / 0	0 / -150	53 / -80	18 / 0	57 / -85	0 / -39
Upset (B)	14 / -14	0 / -161	61 / -88	29 / 0	71 / -99	0 / -45
Faulted (D)	23 / -23	0 / -168	67 / -93	36 / 0	81 / -109	0 / -49

Anchor EF11-A008 (Train 'B' Backwash)

Service Level	Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (ft-lbs)	My (ft-lbs)	Mz (ft-lbs)
Normal (A)	0 / 0	0 / -138	32 / -48	5 / 0	44 / -65	17 / 0
Upset (B)	19 / -19	0 / -147	37 / -53	15 / -4	60 / -82	19 / 0
Faulted (D)	31 / -31	0 / -153	41 / -57	22 / -11	71 / -93	21 / 0

Summary of Spring Stiffness Sensitivity Runs - Seismic Case

		Seismic Analysis Output @ 0.5K_{avg} (Half the Average Soil Spring Stiffness Values)							Seismic Analysis Output @ 2K_{avg} (Double the Average Soil Spring Stiffness Values)							ABS(σ_{double} @ 2K_{avg}) - ABS(σ_{half} @ 0.5K_{avg})
FRAME	LOC	$F_{a.half}$ (kip)	$F_{b.half}$ (kip)	$F_{c.half}$ (kip)	$M_{a.half}$ (kip-in)	$M_{b.half}$ (kip-in)	$M_{c.half}$ (kip-in)	σ_{half} (psi)	$F_{a.double}$ (kip)	$F_{b.double}$ (kip)	$F_{c.double}$ (kip)	$M_{a.double}$ (kip-in)	$M_{b.double}$ (kip-in)	$M_{c.double}$ (kip-in)	σ_{double} (psi)	$\Delta\sigma$
1.0	0.0	-32.17	-2.88	2.70	2.16	248.42	-159.48	187.00	-65.19	-3.21	4.84	1.87	340.21	-163.95	301.03	114.03
1.0	14.5	-32.17	-2.74	2.70	2.16	209.34	-118.75	167.74	-65.19	-3.07	4.84	1.87	269.98	-118.39	271.77	104.03
1.0	29.0	-32.17	-2.59	2.70	2.16	170.25	-80.09	149.19	-65.19	-2.93	4.84	1.87	199.75	-74.91	242.99	93.80
2.0	0.0	-32.17	-2.59	2.70	2.16	170.25	-80.09	149.19	-65.19	-2.93	4.84	1.87	199.75	-74.91	242.99	93.80
2.0	18.0	-32.17	-1.94	2.70	2.16	121.73	-39.25	127.91	-65.19	-2.28	4.84	1.87	112.57	-28.07	208.62	80.71
38.0	57.3	-11.98	-4.75	0.24	14.49	16.54	249.26	207.56	-13.51	-4.13	0.12	6.92	6.87	235.48	201.24	-6.32
39.0	0.0	-11.82	5.12	0.22	-2.00	21.94	249.26	207.16	-12.47	6.65	0.10	-0.47	9.75	235.48	198.55	-8.61
26.0	72.0	-10.61	0.51	-3.72	-4.07	234.17	19.12	193.29	-12.79	0.62	-4.01	-3.36	221.57	14.57	189.77	-3.52
27.0	0.0	-10.13	0.51	4.87	10.64	234.17	16.40	192.06	-11.88	0.62	6.21	7.93	221.57	12.68	187.42	-4.64
14.0	43.0	-9.48	-0.54	4.59	-3.09	-218.94	2.68	179.06	-11.44	-0.58	5.73	1.42	-223.10	6.17	187.09	8.03

NOTES:

1) All forces and moments are from SAP2000 output and are in local coordinates where a=axial, b=vertical and c=transverse.

2) Only ten highest stress locations are summarized.

3) Stress intensification factor of 2.0 used for mitered elbow locations and 1.0 for straight pipe locations.

Summary of Spring Stiffness Sensitivity Runs - Thermal Case

		Thermal Analysis Output @ $0.5K_{avg}$ (Half the Average Soil Spring Stiffness Values)							Thermal Analysis Output @ $2K_{avg}$ (Double the Average Soil Spring Stiffness Values)							ABS(σ_{half} @ $0.5K_{avg}$) - ABS(σ_{double} @ $2K_{avg}$)
FRAME	LOC	$F_{a.half}$ (kip)	$F_{b.half}$ (kip)	$F_{c.half}$ (kip)	$M_{a.half}$ (kip-in)	$M_{b.half}$ (kip-in)	$M_{c.half}$ (kip-in)	σ_{half} (psi)	$F_{a.double}$ (kip)	$F_{b.double}$ (kip)	$F_{c.double}$ (kip)	$M_{a.double}$ (kip-in)	$M_{b.double}$ (kip-in)	$M_{c.double}$ (kip-in)	σ_{double} (psi)	$\Delta\sigma$
38.00	57.31	-49.86	-15.80	0.46	28.82	21.23	828.82	714.26	-51.38	-13.27	-0.16	10.48	5.04	747.91	660.53	53.73
39.00	0.00	-46.40	24.15	0.36	3.58	35.40	828.83	705.35	-45.68	27.01	-0.25	2.26	10.98	747.91	645.87	59.48
26.00	72.01	-45.94	0.58	-14.41	-3.28	797.97	19.85	682.02	-50.25	0.65	-13.74	-2.88	725.58	13.63	641.88	40.14
15.00	0.00	-43.67	-0.75	-14.54	-3.28	-803.15	-6.67	679.67	-47.48	-0.61	-14.38	-2.88	-750.49	5.54	652.28	27.39
27.00	0.00	-42.68	0.58	22.30	11.72	797.97	16.36	673.62	-45.25	0.65	25.82	7.61	725.58	11.67	629.03	44.59
14.00	42.96	-41.16	-0.75	20.60	-7.03	-803.15	-2.39	673.22	-43.74	-0.61	23.41	1.88	-750.49	5.95	642.66	30.56
47.00	0.00	-47.23	-0.05	19.84	3.31	760.15	-2.26	658.44	-50.50	-0.03	21.27	3.05	659.35	-0.64	595.65	62.79
46.00	36.07	-47.15	-0.05	-20.04	3.93	760.15	0.80	658.22	-50.45	-0.03	-21.39	2.58	659.35	1.74	595.52	62.70
37.00	0.00	-45.61	-18.27	1.10	28.90	86.65	-759.26	657.49	-50.10	-19.16	1.67	10.57	55.93	-727.53	644.34	13.15
36.00	41.03	-45.18	19.30	1.10	-40.77	81.74	-759.26	656.39	-48.99	21.85	1.67	-32.04	47.04	-727.53	641.49	14.90

NOTES:
1) All forces and moments are from SAP2000 output and are in local coordinates where a=axial, b=vertical and c=transverse.
2) Only ten highest stress locations are summarized.
3) Stress intensification factor of 2.0 used for mitered elbow locations and 1.0 for straight pipe locations.

Enclosure 3

Letter from Dow Chemical Company (with attachments)

Z. Jimmy Zhou, Ph. D

The Dow Chemical Company
Plastics TS&D NA
2301 N. Brazosport Blvd.
Freeport, TX 77541

June 24, 2008

Mr. Matthew D. Brandes
Mechanical Design Engineer
Nuclear Engineering
Callaway Plant
Ameren UE
PO Box 620, CA-460
Fulton, MO 65251

Dear Mr. Brandes,

The purpose of this letter is to share the fusion qualification data of CONTINUUM DGDA 2490 and DGDA 2492 using the fusion procedure of PPI TR-33, Generic Butt Fusion Joining Procedure for Field Joining of Polyethylene Pipe. Attached are the fusion qualification and testing reports.

The fusion temperature window in PPI TR-33 is from 400 °F to 450 °F. The interfacial stress is from 60 psi to 90 psi. Fusion tests have been done at the four corners of the fusion window: 400 °F/60 psi, 400 °F/90 psi, 450 °F/60 psi, and 450 °F/90 psi to cover all the fusion conditions. The pipe samples used range from 1" up to 22". The fusion joints were made by McElroy, the fusion machine manufacturer, the pipe and fittings manufacturers, the installation contractors, as well as Dow Chemical. The evaluation and testing of the joints were conducted by fusion machine manufacturer, independent testing firms, pipe and fitting manufacturers, contractors, and Dow Chemical as well. The joint test ranges from tensile, impact tensile, quick burst, sustained pressure testing (up to more than 1 years testing at elevated temperatures). The failures of the sustained pressure testing samples were on the pipe section, not in the joints.

PPI TR-33 fusion procedure has been used for DGDA 2490/2492 pipe since 2002 for natural gas pipe, oil and gas collection, industrial pipe, and mining applications without any issues.

Based on the fusion testing data and the field application experience, high quality fusion joints can be made for DGDA 2490/2492 pipe using PPI TR-33. The field conditions vary, which include the ambient temperatures and wind variables. The specific fusion condition may be selected based on the specific job environment. However, the PPI TR-33 fusion window shall cover all the application conditions so that high quality joints are made.

If you have any questions or comments, please do not hesitate to call me.

Yours very truly,

Z. Jimmy Zhou

Z. Jimmy Zhou
Sr. Development Specialist
(979) 238-7410 (office)
(281) 467-8659 (cell)
zjzhou@dow.com

Attachment:

1. CONTINUUM DGDA 2490 Gas Pipe Qualification
2. McElroy Fusion Qualification Report
3. 8" Pipe Fusion Testing Report
4. "New Products, New Horizons: HDPE Resins for Natural Gas Piping"

CC: Lonnie J. Corley, Construction Supervisor, Ameren UE

DOW

TECHNICAL REPORT

Continuum™
Bimodal Polyethylene Resins

CONTINUUM* DGDA-2490 BK 100

For

Natural Gas Pipe and Fittings

<u>Compliance with</u>

ASTM D2513-04 "Standard Specification for the Thermoplastic Gas Pressure Pipe, Tubing and Fittings"

PPI TR-33 "Generic Butt Fusion Joining Procedure for Polyethylene Gas Pipe"

PPI TR-41 "Generic Saddle Fusion Joining Procedure for Polyethylene Gas Pipe",

And

Department of Transportation (DOT) CFR49, Part 192

TABLE OF CONTENTS

1. Scope

1.1 The scope of this document is to provide data that the pipe manufactured from Dow CONTINUUM DGDA-2490 Bimodal Resin is in compliance with ASTM D2513-04 for natural gas distribution as a PE3408 pipe. The resin also meets the requirements in ASTM D 2513-04 Appendix X3 and ISO 4437 as a PE 100 gas pipe. In addition, the heat fusion of DGDA-2490 pipe has been qualified per the Department of Transportation (DOT) CFR 49, Part 192, §192.273(b) and §192.283.

1.2 The butt fusion of DGDA-2490 pipe to other materials has proven to be acceptable using the same testing protocol as documented in the Plastics Pipe Institute (PPI) Technical Report (TR) 33, "Generic Butt Fusion Joining Procedure for Polyethylene Gas Pipe".

1.3 The saddle fusion of PE 2406 and PE 3408 materials to DGDA-2490 pipe has proven to be acceptable using the same testing protocol as documented in PPI TR-41, "Generic Saddle Fusion Joining Procedure for Polyethylene Gas Pipe".

1.4 This document is intended to qualify CONTINUUM DGDA-2490 Bimodal Resin for natural gas piping. The pipe samples used were from several pipe manufacturers. Dow Pipe Technology Center, independent testing firms, pipe manufacturers, and contractors generated the data.

1.5 This document is not intended to qualify any specific pipe manufacturers although pipe samples made from several pipe manufacturers were used. Qualification of pipe and fittings made by a given pipe manufacturer needs to use all samples from the same pipe manufacturer.

2. References

2.1 The following references are applicable to this report:

- ASTM D 2513-04, "Standard Specification for the Thermoplastic Gas Pressure Pipe, Tubing and Fittings"
- ISO 4437:1997, "Buried Polyethylene (PE) Pipes for the Supply of Gaseous Fuels – Metric Series – Specifications"
- PPI TR-33, "Generic Butt Fusion Joining Procedure for Polyethylene Gas Pipe"
- PPI TR-41, "Generic Saddle Fusion Joining Procedure for Polyethylene Gas Pipe"
- DOT CFR 49, Part 192, §192.273, §192.283, §192.285

3. Summary

3.1 The documentation of materials and the test results contained herein indicate that CONTINUUM DGDA-2490 piping products meet the requirements of ASTM D 2513-04, PPI TR-33 and PPI TR-41.

3.2 For qualification under PPI TR-33, butt fusions were made from samples using CONTINUUM DGDA-2490 pipe. The butt fusion joints included like and unlike materials under the parameters of TR-33 and proved to be successful joints.

3.3 Saddle fusions were qualified in accordance with PPI TR-41 by preparing samples of "unlike" materials and tested in accordance with DOT CFR 49, Part 192. All fusions proved to be successful joints.

3.4 Becetel in Belgium conducted the S-4 Rapid Crack Propagation (RCP) test on 10" SDR 11 pipe. The critical temperature was –17°C at the internal pressure of 10 bar, meeting ISO 4437 requirement and the requirement in Northeast Gas Utilities End Use Specification. ASTM F 2231, the modified Charpy test for measuring RCP property, is used as a quality control method for RCP resistance.

3.5 PENT test was conducted on CONTINUUM DGDA-2490 resin materials. All samples had >6000 hour PENT, meeting the requirement of 500 hours in Northeast Gas (NE) Utilities End Use Specification and ASTM D 2513-04. Accelerated PENT at 3 MPa is used as a quality control method for SCG resistance.

4. Analysis/Discussion

4.1 ***General***

The following section numbers used correspond to the applicable section numbers as listed in ASTM D 2513-04. It includes the requirements in the main body for plastic pipe and fittings and the additional requirements as listed in Annex A1 and Appendix X3 for PE gas pipe and fittings. Each requirement includes the supporting documents with a brief explanation of results. The documents are attached as Appendices to this document.

4.2 **Material Requirements (see Appendix A)**
ASTM D 2513-04 Section:

4.1 ***General***
DGDA-2490 pipe material is listed by PPI as PE 3408 and PE 100 pipe.

A1.3.1 ***Classification***
DGDA-2490 material is classified in accordance with ASTM D 3350 with cell classification of 345564C and meets the requirements of Table A1.2 of D 2513-04.

A1.3.2 ***Short and Long Term Properties***
Material has shown to meet the requirements of Table 1.3 as a PE 3408.

A1.3.3 ***Hydrostatic Design Basis (HDB) Substantiation***

Pipe product has been substantiated in accordance with ASTM D 2837. Asterisk (*) listing is granted by PPI (See PPI TR-4) for meeting the substantiation of linearity of long term hydrostatic strength (LTHS) at 73°F for 50 years.

A1.3.4 ***Qualification for LPG Service***

Pipe product has been qualified in accordance with A1.3.3 and carries a recommended HDB at 140°F for 1000 psi in accordance to Section 5.6 of D 2513-04.

A1.3.5 ***Slow Crack Growth Resistance***

Samples subjected to conditions in ASTM F 1473 per this specification exceed an average of 100 hours as shown by the attached test data. In addition, they also exceed the 500-hour requirement in the NE Utilities End Use Specification.

A1.3.6 ***Additive Classes***

Pipe specimens meet the requirements of Class C as defined in ASTM D 3350 as shown by the attached test data.

ISO 4437 Table 1

Rapid Crack Propagation (RCP) Resistance

S-4 test data from Becetel, Belgium exceed the critical pressure requirement of 4.2 bar for PE 100 pipe. They also exceed the critical temperature requirement of 20°F by the NE Gas Utility End Use Specification.

4.3 Requirements for Pipe and Fittings (see Appendix B)

ASTM D 2513-04 Section:

5.1 **General**

Product is supplied in either coils or straight lengths.

5.2 ***Workmanship***

The pipe is homogeneous throughout and free of visible cracks, holes, foreign inclusion, blisters, dents or other injurious defects.

5.3 ***Pipe and Tubing Dimensions***

Dimensions for pipe samples are specified by wall thickness and outside diameter (see Appendix B). Quality pipe made from DGDA-2490 meets the requirements for diameters, toe-in, wall thickness, wall thickness eccentricity range, and ovality.

5.4 ***Sustained Pressure***

The pipe does not fail as defined in Test Method D 1598 when tested in accordance with 6.6 of ASTM D 2513-04 (Refer to A1.5.3 above). In addition, elevated sustained pressure testing was performed at 176°F per ASTM D 1598 with specimens subjected to a hoop stress of 670 $\pm$ 10 psi with no loss in pressure for a test duration of 170 hours. Test results for both sustained and elevated pressure tests are located in Appendix B. DGDA-2490 pipe exceeds the requirements.

ISO 4437 Table 6

Hydrostatic Strength

PE 100 pipe shall not fail before 100 hours at 20°C and 1800 psi, 165 hours at 80°C and 800 psi, and 1000 hours at 80°C and 670 psi. DGDA-2490 exceeds the requirements.

ASTM D 2513-04 Section:

5.5 ***Elevated Temperature Service***

PPI Hydrostatic Design Basis (HDB) has been determined in accordance with Test Method D 2837 for use of material up to 140°F (60°C). Material has been categorized as CEC (or CEE) in accordance with Table 4 of ASTM D 2513-04.

X3.5.1 ***Elevated Temperature Service***

In addition to MRS classification using the ISO 12162 standard conditions of 20°C and 50 years, the MRS can be determined at other desired temperature or time conditions as denoted by MRS (θ, t). The MRS (θ, t) is the categorized MRS value for a material at a temperature of θ °C and a time of t years. In addition to the pipe category per table 4 of ASTM D 2513-04, the pipe category using the MRS designation as noted in Table X3.2 may be used. DGDA-2490 pipe has been categorized as CJC (or CJE) in accordance with Table X3.2 of ASTM D2513-04. (Note that ISO and PPI have changed MRS (θ, t) to CRS (θ, t))

A1.5.1 ***Conditioning***

Samples were conditioned in accordance with 6.3 when conditioning of samples was required.

A1.5.2 ***Minimum Hydrostatic Burst Pressure/Apparent Tensile Strength (Quick Burst)***

Pipe samples failed in a ductile manner when tested in accordance with ASTM D 1599 as shown by the attached test data (See Appendix B).

A1.5.3 ***Sustained Pressure 73°F (23°C)***

Pipe samples did not fail in less than 1000 hours when tested in accordance with ASTM D 1598. As shown by the attached test data, pipe specimens were subjected to stress of 1600 psi (See Appendix B).

A1.5.4 ***Melt Index***

Melt index of pipe complies with Table 4 and listing of pipe category CEC (or CEE) (See Appendix B).

A1.5.6 ***Thermal Stability***

Pipe exceeds minimum induction temperature of 428°F (220°C) when tested in accordance with ASTM D 3350 (See Appendix B).

A1.5.7 ***Outdoor Storage Stability***

Pipe specimens meet the requirements of this specification; therefore, they are suitable for storage exceeding two years from date of manufacture.

A1.5.8 ***Dimensions and Tolerance***

See 5.3

A1.5.9 ***Short Term Pressurization for Sizes above 12"***

Pipe, molded and fabricated fittings shall not fail when tested in accordance with Test Method D 1599 with the hoop stress of 2900 psi for Class 3 density materials. Pipe made from DGDA-2490 exceeds this requirement (See Appendix B).

A1.5.10 ***HDB Validation of PE Pipe***

HDB at 73°F and 140°F was validated using the pipe specimens made by several pipe manufacturers per ASTM D 2837. Validating 1000 psi HDB at 140°F per PPI TR-3 and ASTM D 2837 validated the 1600-psi HDB at 73°F.

A1.5.11 ***Inside Surface Ductility for Pipe***

Samples were conditioned in accordance with D 618 before testing in accordance with A1.5.11.1, A1.5.11.2 and A1.5.11.3

A1.5.11.2 ***Elongation-At-Break Test Method***

Percentage of elongation for specimens exceeds 400% for each test specimen.

A1.5.11.3 ***Thermal Stability Test Methods***

See A1.5.6

4.4 Fusion Qualification (see Appendix C)

The following analysis/discussion lists the supporting documents with a brief explanation to support the qualification of CONTINUUM DGDA-2490 pipe according to the generic butt fusion procedure, PPI TR-33.

4.4.1. ***Plastics Pipe Institute TR-33***

This report describes the scope, testing program for the evaluation of pipe fusion of like and unlike materials, pipe sizes, conclusion, resin types, pipe manufacturers and the generic buff fusion procedure itself.

The following butt fusion combinations were made per the guidelines of TR-33:

1" SDR 11 DGDA-2490 pipe with 1" SDR 11 CP TR 418 PE 2406 pipe
1" SDR 11 DGDA-2490 pipe with 1" SDR 11 Atofina 3344 PE 3408 pipe
1" SDR 11 DGDA-2490 pipe with 1" SDR 11 Drisco 8100 PE 3408 pipe

These fusions were subjected to the testing programs of TR-33 for evaluation of the butt fusions. This included the following testing procedures:

ASTM D 1599-99 "Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing and Fittings"

ASTM D 1598-02 "Time-to-Failure of Plastic Pipe under Constant Internal Pressure"

ASTM D 638-01 "Tensile Properties of Plastics"

ASTM D 1822-99 "Tensile-Impact Energy to Break Plastics and Electrical Insulating Materials"

The results of the above references testing standards are located in Appendix C of this report.

The following analysis/discussion lists the supporting documents with a brief explanation to support the qualification of CONTINUUM DGDA-2490 pipe according to the generic saddle fusion procedure, PPI TR-41.

4.4.2 ***Plastics Pipe Institute TR-41***

This report describes the scope, testing program for the evaluation of pipe fusion of like and unlike materials, pipe sizes, conclusions, resin types, pipe manufacturers and the generic saddle fusion procedure itself.

The following saddle fusions were made per guidelines of TR-41:

Quick Burst Test

Saddle Fusion Tap Tee	2" SDR 11 Pipe	End Cap	
		Material	**Fusion Type**
DGDA-2490 BK 100	DGDC-2480 3408	Solvay K44-08-123	Socket
DGDA-2490 BK 100	DGDC-2480 3408	Solvay K44-08-123	Butt
DGDA-2490 BK 100	Atofina 3344 PE 3408	Solvay K44-08-123	Socket
DGDA-2490 BK 100	UAC 2000 (TR-418)	TR-418	Socket

Knock-Out Test

Saddle Fusion Tap Tee	2" SDR 11 Pipe
DGDA-2490 BK 100	DGDC-2480 BK 3408
DGDA-2490 BK 100	DGDC-2480 BK 3408
DGDA-2490 BK 100	Atofina 3344 PE 3408
CP TR-480 PE 3408	DGDC-2480 BK 3408
CP TR-480 PE 3408	DGDC-2480 BK 3408

These fusions were subjected to the testing program of TR-41 for evaluation of the saddle fusions. This included the following testing procedures:

ASTM D 1598-02 "Time-to-Failure of Plastic Pipe under Constant Internal Pressure"

The results of the above references testing standard are located in Appendix C of this report.

4.5 Fitting Qualification (see Appendix D)

The following analysis/discussion lists the supporting documents with a brief explanation to support the qualification of CONTINUUM DGDA-2490 material according to the requirements of ASTM D 3261-97 and the generic butt fusion procedure, PPI TR-33.

4.5.1 ***ASTM D 3261-97***

This specification covers polyethylene (PE) butt fusion fittings for use with polyethylene pipe (IPS and ISO) and tubing (CTS). Included are the requirements for materials, workmanship, dimensions, marking, sustained pressure, and burst pressure.

4.5.2 ***Plastics Pipe Institute TR-33***

This report describes the scope, testing program for the evaluation of pipe fusion of like and unlike materials, pipe sizes, conclusion, resin types, pipe manufacturers and the generic buff fusion procedure itself.

The following butt fusion combinations were made per the guidelines of TR-33:

1" SDR 11 DGDA-2490 fitting to 1" SDR 9 DGDA-2490 pipe
2" SDR 11 DGDA-2490 fitting to 2" SDR 9 DGDA-2490 pipe

These fusions were subjected to the testing programs of TR-33 for evaluation of the butt fusions. This included the following testing procedures:

ASTM D 1599-99 "Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing and Fittings"

ASTM D 1598-02 "Time-to-Failure of Plastic Pipe under Constant Internal Pressure"

ASTM D 638-01 "Tensile Properties of Plastics"

ASTM D 1822-99 "Tensile-Impact Energy to Break Plastics and Electrical Insulating Materials"

The results of the above references testing standards are located in Appendix C of this report.

5. Conclusion

From the data that are presented in this report, CONTINUUM DGDA-2490 bimodal material exceeds the requirements of ASTM D 2513-04 as PE 3408 pipe. It also exceeds the key performance requirements in ISO 4437 for PE 100 pipe. In addition, it meets the requirements listed in the Northeast Gas Utility End Use Specification for operation pressures, operation temperatures, SCG resistance, and RCP resistance.

From the data that are presented in this report, samples of pipes extruded from a compound of 93.5% CONTINUUM DGDA-2490 and 6.5% DFNF-0092 from PolyOne or Ampacet by several pipe manufacturers have shown to meet or exceed the requirements of ASTM D 2513-04 as PE 3408 pipe. It also exceeds the key performance requirements in ISO 4437 for PE 100 pipe.

In addition, the butt fusion that were made with like and unlike materials met the requirements of TR-33, "Generic Butt Fusion Joining Procedure for Polyethylene Gas

Pipe." Saddle fusions also proved to be acceptable per requirements of DOT, CFR 49, Part 192, §192.283 and met the requirement of PPI TR-41, "Generic Saddle Fusion Joining Procedure for Polyethylene Gas Pipe."

From the data that are presented in this report, samples of fittings made by Central Plastics, Rahn Plastics and Perfection from black CONTINUUM DGDA-2490 material (93.5% DGDA-2490 NT resin and 6.5% DFNF-0092 black masterbatch) met the requirements of ASTM D 3261, "Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing" and PPI TR-33, "Generic Butt Fusion Joining Procedure for Polyethylene Gas Pipe".

Natural gas pipe and fittings manufactured from this material shall have a PPI dependent listing supported by The Dow Chemical Company and granted by PPI. It shall be marked in accordance with ASTM D 2513-04 Section 7.1 and A1.6.1. The pipe shall be identified by a trade name of the pipe manufacturer that is listed by PPI.

APPENDIX A

DATA FOR MATERIAL QUALIFICATION

Plastics Pipe Institute (PPI) TR-4 Pressure Rating Listing

HDB Listing

CONTINUUM DGDA-2490 BK 100 is listed in Plastics Pipe Institute (PPI) TR-4 as a PE 3408 pipe material with 1600 psi HDB at 73°F. As indicated by the asterisk listing (*), it is validated for the linearity of the long term hydrostatic strength (LTHS) at 73°F for 50 years. In addition, it has 1000 psi HDB at 140°F.

Company Name	**Material Designation**	**Temp. (F)**	**HDB (psi)**	**Grade**	**Expiration Date**
Dow Chemical Co	CONTINUUM DGDA 2490 BK 100	73	1600	S*	12/31/05
Dow Chemical Co	CONTINUUM DGDA 2490 BK 100	140	**1000**	S	12/31/05

MRS Listing

Company Name	**Material Designation**	**Temperature (F)**	**HDB (psi)**	**Grade**	**Expiration Date**
Dow Chemical Co	CONTINUUM DGDA 2490 BK 100	68	10	S	12/31/05

CRS (θ, t) Listing

For design purposes, the CRS (θ, t) may be determined at other desired temperatures (θ) or time (t) conditions. The CRS (θ, t) is the categorized value of the ISO 9080 σ_{lpl} for a material at a temperature of θ F (°C) and a time of t years, using the extrapolation limits of ISO 9080.

Company Name	**Material Designation**	**Temp (F)**	**Time (years)**	**CRS**	**Grade**	**Expiration Date**
Dow Chemical Co	CONTINUUM DGDA 2490 BK 100 (20 C, 100 years)	68	100	10	S	12/31/06
Dow Chemical Co	CONTINUUM DGDA 2490 BK 100 (40 C, 90 years)	105	90	8	S	12/31/06
Dow Chemical Co	CONTINUUM DGDA 2490 BK 100 (60 C, 11years)	**140**	**11**	**6.3**	S	12/31/06

Cell Classification in Accordance with ASTM D 3350

Property	Test Method	Value	Cell Classification per ASTM D3350
Density, g/cc	ASTM D 1505	0.949	3
Melt Index, I_2	ASTM D1238	0.08	4
Flexural Modulus, MPa (psi)	ASTM D 790, method 1, Procedure B	1034 (150,000)	5
Tensile strength at yield, MPa (psi)	ASTM D 638	24.8 (3600)	5
Slow Crack Growth PENT (hours), molded plaque, 80°C, 2.4 MPa	ASTM F 1473	>6000	6
Hydrostatic Design Classification HDB, psi (73°F) MRS, MPa (20°C)	 ASTM D 2837 ISO 9080	 1600 10	 4 6

PENT Data

Test done by Dow

Year Tested	Resin	Blend number	PENT (hours)	Specimen
		2.4 MPa and 80°C		
2002 – 2003	DGDA-2490		9,451	
	DGDA-2490		8,832	on test
	DGDA-2490		9,042	on test
	DGDA-2490		9,271	on test
	DGDA-2490		9,049	Stopped, non-failure
	DGDA-2490		9,049	Stopped, non-failure
	DGDA-2490		9,050	Stopped, non-failure
	DGDA-2490		9,050	Stopped, non-failure
	DGDA-2490		24,900	on test

S-4 RCP Property

Material Designation	Tc, °C	Pc, bar	Pc, bar
	ISO 13477	ISO 4437	ISO 13477
DGDA-2490	< -17	4.2	>12

APPENDIX B

DATA FOR PIPE AND FITTINGS

Dimensions and Tolerance

2" DGDA-2490 pipes made by Uponor

Sample #	Actual OD, in	Maximum OD, in	Minimum OD, in	Maximum Wall, in	Minimum Wall, in	Out-of-Round	Ovality	Eccentricity
1	2.378	2.380	2.375	0.234	0.225	0.005	0.2%	3.8%
2	2.378	2.380	2.375	0.232	0.226	0.005	0.2%	2.6%

4" DGDA-2490 pipes made by Rinker Materials

Sample #	Actural OD, in	Maximum OD, in	Minimum OD, in	Maximum Wall, in	Minimum Wall, in	Out-of-Round	Ovality	Eccentricity
1	4.510	4.515	4.505	0.455	0.412	0.010	0.2%	9.5%
2	4.510	4.515	4.505	0.450	0.409	0.010	0.2%	9.1%

6" DGDA-2490 pipes made by Rinker Materials

Sample #	Actural OD, in	Maximum OD, in	Minimum OD, in	Maximum Wall, in	Minimum Wall, in	Out-of-Round	Ovality	Eccentricity
1	6.628	6.629	6.626	0.653	0.622	0.003	0.0%	4.7%
2	6.628	6.629	6.626	0.652	0.620	0.003	0.0%	4.9%

OIT@ 210 C: 43 minutes

ASTM D 2513-04, Section 5.5 Sustained Pressure
Since pipes do not fail at 1600psi, ISO 4437 test condition for PE 100 is used
(1800 psi @ 23°C for PE 100)
Pipe samples were made by Dow Chemical, Oil Creek, Performance Pipe, Rinker Materials, CO-EX and Quail

Date	Wall Thickness (in)	O. D. (in)	Line Pressure (psi)	Hoop Stress (psi)	Failure Time (hours)	Type of Failure
June 2000	0.130	1.315	395	1800	173	Non-Failure
June 2000	0.130	1.315	395	1800	173	Non-Failure
June 2000	0.130	1.315	395	1800	173	Non-Failure
July 2001	0.125	1.315	378	1800	349	Ductile
July 2001	0.125	1.315	378	1800	333	Ductile
July 2001	0.125	1.315	378	1800	435	Ductile
October 2002	0.121	1.319	364	1800	110	Non-Failure
October 2002	0.121	1.319	364	1800	181	Non-Failure
October 2002	0.121	1.319	364	1800	102	Non-Failure

ASTM D 2513-04, Section 5.6 Elevated Temperature Service
Since pipes do not fail at 670psi, ISO 4437 test condition for PE 100 is used
Pipe samples were made by Dow Chemical, Oil Creek, Performance Pipe, Rinker Materials, CO-EX and Quail
(800 psi @ 80°C for PE 100)

Date	Wall Thickness (in)	O. D. (in)	Line Pressure (psi)	Hoop Stress (psi)	Failure Time (hours)	Type of Failure
March 2000	0.125	1.305	169	800	10,852	Non-Failure
March 2000	0.125	1.305	169	800	10,908	Non-Failure
March 2000	0.125	1.305	169	800	10,946	Non-Failure
April 2000	0.121	1.305	163	800	5,754	Ductile
April 2000	0.121	1.305	163	800	5,569	Non-Failure
April 2000	0.121	1.305	163	800	5,982	Non-Failure
July 2000	0.130	1.315	175	800	3,012	Ductile
July 2000	0.130	1.315	175	800	10,699	Non-Failure
July 2000	0.130	1.315	175	800	8,200	Ductile
August 2001	0.125	1.315	168	800	3,125	Non-Failure
August 2001	0.125	1.315	168	800	3,174	Non-Failure
August 2001	0.125	1.315	168	800	3,861	Non-Failure

Quick Burst of Butt Fusion Jointed 22" SDR 9 DGDA-2490 Pipes made by Rinker

Pipe Sample	DGDA-2490 BK 100
Pipe Outside Diameter, inches	22.025
Minimum Wall Thickness, inches	2.496
Test Condition	23°C
Internal Pressure, psig	1090
Hoop Stress, psi	4264

Evaluation of Fusion Welds Generated at Michigan Pipe Using 21" Diameter SDR 11 Pipe Made from DGDA-2490 by Quail Piping at Kingman, Arizona

	Fusion Joint #1 (450° F, 9 min @ 75psi)	**Fusion Joint #2** (400° F, 10 min @ 75psi)	**Pipe Sidewall** (control)
A. Dow PTL			
Yield Strength, psi (stdev)	3491 (141)	3499 (67)	3607 (74)
Break Strength, psi (stdev)	3865 (365)	3934 (153)	4247 (133)
Elongation at Break, % (stdev)	590 (41)	610 (25)	647 (20)
Tensile Impact, @ 23°C ft-lb./cu in. ft-lb./sq. in.	483 227	484 228	489 230
B.TRI/Environmental, Inc			
Yield Strength, psi (stdev)	3673 (253)	3561 (311)	3261 (167)
Break Strength, psi (stdev)	3533 (858)	3485 (817)	3801 (356)
Elongation at Break, % (stdev)	NA	NA	NA

VALIDATION: HYDROSTATIC BURST TEST OF CONTINUUM DGDA-2490

Resin Manufacturer: Dow — **Type: A-2490 BK**
Black Masterbatch Producer: PolyOne — **Type: DFNF-0092**
Pipe Producer: Quail — **Rework: 0%**
Sample Size and Length: 1" SDR 11 x 18" — **Temperature: 23 C**
Conditioning: > 48 hours — **Test Fluid: Water**
Date: July 2001 — **Tested: Dow's Laboratory**

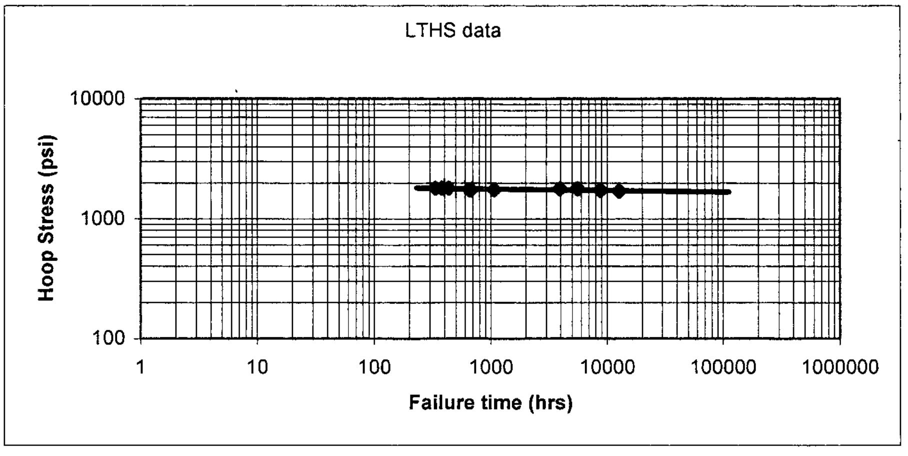
Data Identification: **DGDA-2490 BK Quail**

Pipe OD (inches):	1.315
Pipe wall thickness (inches):	0.125
SDR:	10.52
SIDR:	8.52
Date of test:	7/1/2001
Test Temperature (deg. C):	23
Number of Data points:	15

note: both "r" and "r2" use predicted failure time vs. actual failure time.

Correlation coefficient (r):	0.8938754
r2 value:	0.7990131
Ratio (LCL/LTHS)	0.9357276

Long Term Hyd. Stress (1,000 hours)	1783
Long Term Hyd. Stress (10 years)	1639
Long Term Hyd. Stress (100,000 hours)	**1635**
Long Term Hyd. Stress (50 years)	1591
Lower Confidence Limit (97.5%)	1530
Hydrostatic Design Basis	1600



VALIDATION: HYDROSTATIC BURST TEST OF CONTINUUM DGDA-2490

Resin Manufacturer: Dow
Black Masterbatch Producer: PolyOne
Pipe Producer: Oil Creek
Sample Size and Length: 1" SDR 11 x 18"
Conditioning: > 48 hours
Date: November 2003

Type: A-2490 BK
Type: DFNF-0092
Rework: 0%
Temperature: 60 C
Test Fluid: Water
Tested: Dow's Laboratory

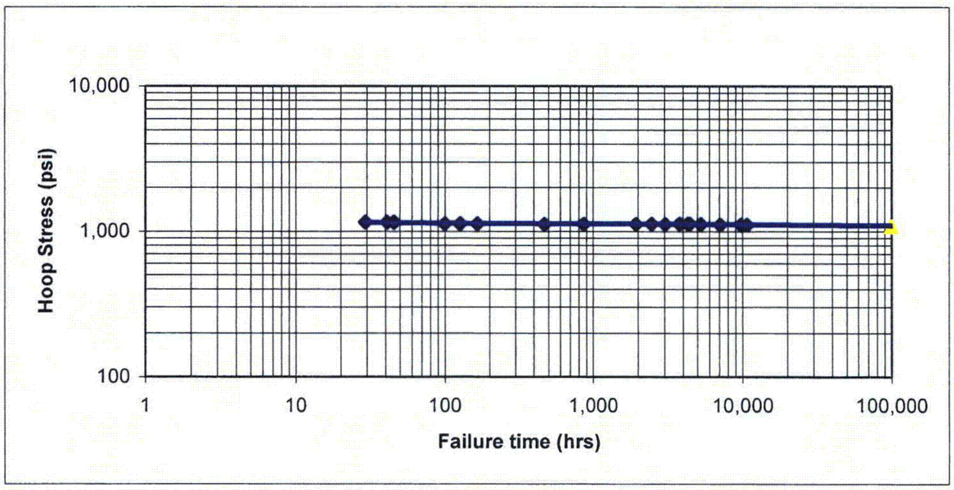
Data Identification: **DGDA-2490 BK 100 Oil Creek**

Pipe OD (inches):	1.196
Pipe wall thickness (inches):	0.073
SDR:	16.38
SIDR:	14.38
Date of test:	11/3/2003
Test Temperature (deg. C):	**60**
Number of Data points:	19

note: both "r" and "r2" use predicted failure time vs. actual failure time.

Correlation coefficient (r):	0.8768598
r2 value:	0.7688831
Ratio (LCL/LTHS)	0.985369382

Long Term Hyd. Stress (1,000 hours)	1120
Long Term Hyd. Stress (10 years)	1082
Long Term Hyd. Stress (100,000 hours)	**1080**
Long Term Hyd. Stress (50 years)	1068
Lower Confidence Limit (97.5%)	1065
Hydrostatic Design Basis	1000



APPENDIX C

DATA FOR FUSION QUALIFICATION

Cross-Fusion of one-inch, SDR 11, CONTINUUM DGDA-2490 BK 100 With Benchmark Pressure one-inch, SDR 11 Pipes

DGDA-2490 BK cross-fused with	Test Reference	Test Conditions	Time to Failure (Hours)	Mode of Failure (Brittle/Ductile)
PE 2406 23 C				
TR 418 PE 2406	ASTM D3261 (Table 7, footnote A)	23 C, 1320 psi	5544	No failure
			5544	No failure
			5544	No failure
PE 2406 80 C				
TR 418 PE 2406	ISO 1167 (4.6 MPa)	80 C, 670 psi	5568	No failure
			5568	No failure
			5568	No failure
PE 3408 23 C				
Atofina 3344 PE 3408	ASTM D3261 (Table 7, footnote A)	23C, 1600 psi	4752	No failure
			4752	No failure
[redacted]			[redacted]	[redacted]
Drisco 8100 (Marlex H516 PE 3408)			4752	No failure
			7008	No failure
			7008	No failure
PE 3408 80 C				
Atofina 3344 PE 3408	ISO 1167 (5.5 MPa)	80 C, 800 psi	1981	Brittle failure on Fina pipe, joint intact
			1981	Brittle failure on Fina pipe, joint intact
			3045	Brittle failure on Fina pipe, joint intact
[redacted]			[redacted]	[redacted]
Drisco 8100 (Marlex H516 PE 3408)			2860	Failure at the joint
			4716	Brittle failure on Drisco 8100, joint intact
			7056	No failure
PE 100 23 C & 80 C				
DGDA-2490 BK	ASTM D3261 (Table 7, footnote A)	23 C, 1600 psi	> 10,000	Brittle failure on pipes
	ISO 1167 (5.5 MPa)	80 C, 800 psi	4300	Brittle failure on pipes

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Executive Summary:

The purpose of this test was to validate the fusion of polyethylene (PE) pipe materials. Samples of Dow PE100/Enhanced PE3408 pipe fused to itself and PE3408 and PE2406 pipe materials were examined through Burst and Sustained Pressure testing. A sample of Dow PE100 PE fused to itself was examined by Tensile testing.

Visual inspection of the butt fused joints was conducted to examine for any signs of unacceptable appearance such as cold fusion, improper alignment, inadequate roll back, incomplete face off, or insufficient melt. Sustained Pressure testing was conducted in accordance with ASTM D3261-97 according to ASTM D1598-97. Six specimens were tested at 80 °C, 115 psig for 1000 hours. Burst testing was conducted in accordance with ASTM D1599-99, Procedure A. Tensile testing was conducted in general accordance with ISO 13953:2001(E) for 20" diameter pipe sections, at the speed of 5 mm/min with fusion beads intact.

Based on visual analysis, the samples all appear to be adequately fused. This is confirmed by the burst test and sustained pressure test results for the 2" pipe samples and the tensile test results for the 20" pipe. All the 2" pipe specimens passed the Sustained Pressure Test requirements of ASTM D3261-97, Section 10.5.2 and the Burst Pressure Test requirements of ASTM D3261-97, Section 10.5.3. All Tensile Test failures were ductile based on reference to ISO 13953:2001(E).

Based on the testing and analysis conducted the following conclusions can be drawn:

1. The 2" pipe butt fusions of the PE100/Enhanced PE3408 material to itself and PE3408 and PE2406 pipe materials meet the Sustained Pressure and Burst Test requirements of ASTM D3261-97.

2. Tensile testing of the butt fused joints prepared from the 20" diameter pipe show that the butt fused area has similar or greater tensile strength compared to the solid (wall) pipe control (samples) and that all failures at the fusion interface are ductile in nature.

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JANA LABORATORIES INC.

Report No: Project 02-3117 – Final Report

Client: Dow

Date of Issue: January 17, 2003

Purpose of Test:

The purpose of this test was to validate the fusion of polyethylene (PE) pipe materials. Samples of Dow PE100 PE fused to itself and PE3408 and PE2406 pipe materials were examined.

Test Item Identification and Description:

Sample ID	Description	# of Specimens
02-758	Black PE Pipe. Two pieces cut from large diameter pipe 200102016-56-1 Quail Pipe Butt Fusion Sample	2
02-777	Black PE Pipe. One piece cut from large diameter pipe. Dimensions: 16 ½" x 20" x 2". PC 160 C3. ASTM F714-2-A. AZ 12-13-01 QUAIL HD3400	1
02-812	Black PE Pipe. One piece cut from large diameter pipe. Dimensions : 13" x 10" x 2" With fusion in the middle	1
02-813	Black PE Pipe. One piece cut from large diameter pipe. Dimensions : 13" x 5" x 2" With fusion in the middle	1
02-814	2" PE Pipe. Fusion of DGDB-2480 with DGDC-2480 Note: DGDB-2480 pipe has yellow print line and DGDC-2480 pipe has blue print line Blue: SDR11 AWWA C901-96-PC-160	9
02-815	2" PE Pipe. Fusion of DGDC-2480 with DGDC-2480 Note: DGDC-2480 pipe has blue print line SDR 11 PE 3408 2" IPS	11
02-816	2" PE Pipe. Fusion of DGDC-2480 with PE2406 Quail pipe Note: DGDC-2480 pipe has blue print line and PE 2406 is yellow pipe Yellow: QUAIL MD 2400 GAS PIPE PE2406 2" IPS SDR 11 Black: HD 3400 PE3408 2" IPS SDR11	11
02-850	2" PE Pipe. Fusion of DGDB-2480 with DGDC-2480	3

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Test Methods:

Visual inspection of the butt fused joints was conducted to examine for any signs of unacceptable appearance such as cold fusion, improper alignment, inadequate roll back, incomplete face off, or insufficient melt.

Sustained Pressure testing was conducted in accordance with ASTM D3261-97 according to ASTM D1598-97. Six specimens for testing were capped with free end style closures, filled with water, and conditioned for a minimum of 1 hour in water at 176 ± 3.6 °F (80 ± 2 °C). Specimens were internally pressurized with water to 115 psig (0.794 MPa) and tested for 1000 hours. The applied hoop stress was calculated based on the end pipe dimensions.

Burst testing was conducted in accordance with ASTM D1599-99, Procedure A. Five specimens were capped with free end style closures, filled with water, and conditioned for a minimum of 1 hour in water at 73 ± 3.6 °F (23 ± 2 °C). Internal water pressure was ramped uniformly and continuously until the specimen failed between 60 and 70 seconds. The applied hoop stress was calculated based on the end pipe dimensions.

Tensile testing was conducted in general accordance with ISO 13953:2001(E) for the large diameter pipe sections both with and without butt fusion joints. Type B test pieces were machined except that the length of the narrow parallel sided portion was zero due to the constraints in the number of available samples and the machining process. One solid pipe control sample had a narrower end width, however, the region being tested had the same dimensions as all other samples. Four solid pipe control specimens were prepared from Sample 02-777. Seven specimens with butt fused joints were prepared from Samples 02-812, 02-813 and 02-758. Machined samples were conditioned at 73 ± 3.6 °F (23 ± 2 °C) for a minimum of 24 hours prior to testing. Testing was conducted at the speed of 5 mm/min. Fusion beads were not removed. Tensile testing was conducted at an approved outsource laboratory.

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Results:

1. Visual Inspection

Based on visual inspection of the butt fusion joints of the large diameter pipe and the 2" pipes, the pipes appear to be adequately fused. No indication of cold fusion, improper alignment, inadequate roll back, incomplete face off or insufficient melt were observed.

2. Sustained Pressure Test: 2" Butt Fused Pipe Samples

The Sustained Pressure Test results are provided in Tables 2.1, 2.2, and 2.3. All specimens tested exceeded the requirements of D3261 Section 10.5.2.

Table 2.1: Fusion between DGDC-2480(PE100/Enhanced PE3408) and DGDC-2480(PE100/Enhanced PE3408), 80 °C, 115 psig

Specimen	02-815-01	02-815-02	02-815-03	02-815-04	02-815-05	02-815-06	D3261 Section 10.5.2
Hoop Stress (psi)	551	548	551	545	552	553	N/A
Status after 1000 hrs	Non-Failure	Non-Failure	Non-Failure	Non-Failure	Non-Failure	Non-Failure	Pass

N/A: Not-applicable

Table 2.2: Fusion between DGDC-2480(PE100/Enhanced PE3408) and DGDB-2480(PE3408), 80 °C, 115 psig

Specimen	02-814-01	02-814-02	02-814-03	02-814-04	02-814-05	02-814-06	D3261 Section 10.5.2
Hoop Stress (psi)	550	543	549	556	553	562	N/A
Status after 1000 hrs	Non-Failure	Non-Failure	Non-Failure	Non-Failure	Non-Failure	Non-Failure	Pass

N/A: Not-applicable

Table 2.3: Fusion between DGDC-2480(PE100/Enhanced PE3408) and PE2406, 80 °C, 115 psig

Specimen	02-816-01	02-816-02	02-816-04	02-816-05	02-816-06	02-816-10	D3261 Section 10.5.2
Hoop Stress (psi)	554	551	551	546	552	549	N/A
Status after 1000 hrs	Non-Failure	Non-Failure	Non-Failure	Non-Failure	Non-Failure	Non-Failure	Pass

N/A: Not-applicable

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3. Burst Test: 2" Butt Fused Pipe Samples

The Burst Test results are provided in Tables 3.1, 3.2, and 3.3. All the failures occurred in the pipe. None of butt fused joints failed during testing. Testing was conducted between October 18, 2002 and December 9, 2002. For sample 02-816, the PE2406 pipe section expanded significantly during testing such that the pressure reached the peak between approximately 60 and 70 seconds and then stopped increasing. The sample then failed at a later time at a pressure close to the peak pressure. In this case, the peak pressure is recorded as the Burst Pressure. All the failures occurred above the minimum burst pressure requirement of 500 psig in accordance with ASTM D3261-97, Section 10.5.3.

Table 3.1: Fusion between DGDC-2480(PE100/Enhanced PE3408) and DGDC-2480(PE100/Enhanced PE3408), 23 °C

Specimen	02-815-07	02-815-08	02-815-11	02-815-10	02-815-09	Mean (± s.d.)
Date	02-10-18	02-10-18	02-11-06	02-11-06	02-11-06	N/A
Time to Burst (sec)	66	64	69	63	61	N/A
Burst Pressure (psig)	795	780	797	776	789	787 ± 9
Burst Stress (psi)	3807	3729	3832	3718	3759	3769 ± 49
Failure Mode	Ductile	Ductile	Ductile	Ductile	Ductile	N/A

s.d.: Standard deviation
N/A: Not-applicable

Table 3.2: Fusion between DGDC-2480(PE100/Enhanced PE3408) and DGDB-2480(PE3408), 23 °C

Specimen	02-814-08	02-814-07	02-814-09	02-850-01	02-850-02	Mean (± s.d.)
Date	02-11-06	02-11-06	02-11-06	02-12-09	02-12-09	N/A
Time to Burst (sec)	65	62	67	63	61	N/A
Burst Pressure (psig)	800	773	877	969	789	842 ± 82
Burst Stress (psi)	3826	3769	4193	4505	3721	4003 ± 337
Failure Mode	Ductile	Ductile	Ductile	Ductile	Ductile	N/A

s.d.: Standard deviation
N/A: Not-applicable

Table 3.3: Fusion between DGDC-2480(PE100/Enhanced PE3408) and PE2406, 23 °C

Specimen	02-816-07	02-816-11	02-816-09	02-816-03	02-816-08	Mean (± s.d.)
Date	02-11-06	02-11-06	02-11-12	02-11-12	02-12-09	N/A
Time to Burst (sec)	82	69	87	85	71	N/A
Burst Pressure (psig)	637	656	664	654	698	662 ± 22
Burst Stress (psi)	3054	3111	3162	3032	3235	3119 ± 83
Failure Mode	Ductile	Ductile	Ductile	Ductile	Ductile	N/A

s.d.: Standard deviation
N/A: Not-applicable
Note: All failures are located on yellow pipe (PE2406)

4. Tensile Testing: 20" PE100 Pipe Butt Fusion Samples

The Tensile Test results of the 20" diameter pipe sections are provided in Table 4.1. A machined sample prior to the testing and the failed surface area of one of the butt fused pipe specimens are shown in Figure 1 and Figure 2, respectively. All the failures of the butt fused pipe specimens show the same type of failure as shown in Figure 2. Specimens prepared from the solid pipe control failed after necking and elongation. In general, the Tensile Strengths of the fused pipe samples were comparable to those of the solid wall pipe. The average Tensile Strength of the fused samples was 27.5 ± 0.3 N/mm^2 compared to 26.4 ± 0.7 N/mm^2 for the solid wall pipe. The fused samples were tested with the fusion beads intact.

The geometry of the specimens ensures that the stress is concentrated through the jointed region and that ultimate failure is in the vicinity of the joint. All failures occurred at the fusion interface as intended. The failures based on reference to Figure 2 of ISO 13953:2001(E), are all ductile in nature.

Table 4.1: Tensile Test Results

Sample	Tensile Strength (N/mm^2)	Total Extension (mm)	Mode of Failure
Fused 1	28.0	21.4*	Ductile
Fused 2	27.5	30.9	Ductile
Fused 3	27.4	30.5*	Ductile
Fused 4	27.6	32.7	Ductile
Fused 5	27.6	29.2	Ductile
Fused 6	27.4	58.6	Ductile
Fused 7	26.9	37.1	Ductile
Solid Control 1	27.0	106.7	Necking and elongation
Solid Control 2	26.6	130.6	Necking and elongation
Solid Control 3	26.5	98.8	Necking and elongation
Solid Control 4**	25.4	111.3***	Necking and elongation

* The test was stopped when the load dropped by 80% of the peak load, therefore, the total extension is greater than the reported value

** End width is 45 mm with traction hole diameter of 19 mm

*** The area around the traction holes began to elongate during the test due to the narrow end width, therefore the total extension is less than the reported value

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Figure 1: Machined Specimen before Tensile Testing – Butt Fused Specimen

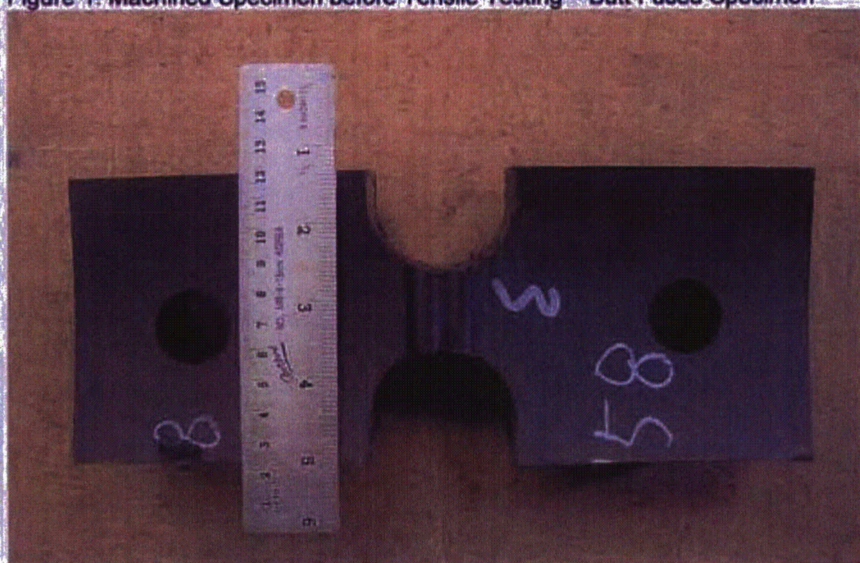
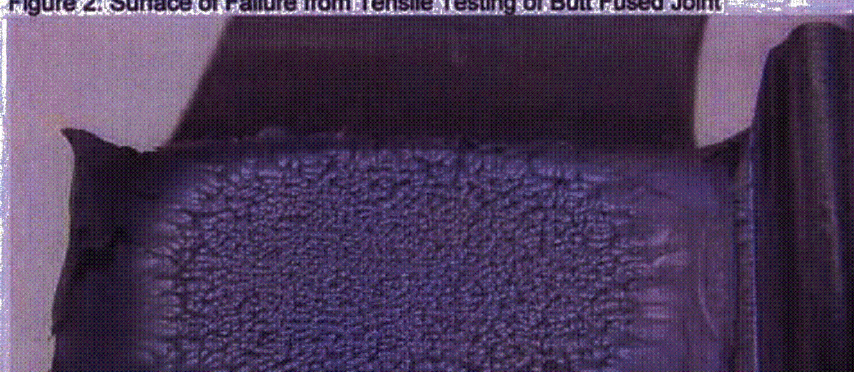


Figure 2: Surface of Failure from Tensile Testing of Butt Fused Joint



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Discussion:

Based on visual analysis, the samples all appear to be adequately fused. This is confirmed by the burst test and sustained pressure test results for the 2" pipe samples and the tensile test results for the 20" pipe. All the 2" pipe specimens passed the Sustained Pressure Test requirements of ASTM D3261-97, Section 10.5.2 and the Burst Pressure Test requirements of ASTM D3261-97, Section 10.5.3. All Tensile failures were ductile based on reference to ISO 13953:2001(E).

Conclusions:

Based on the testing and analysis conducted the following conclusions can be drawn:

1. The 2" pipe butt fusions of the PE100/Enhanced PE3408 material to itself and PE3408 and PE2406 pipe materials meet the Sustained Pressure and Burst Test requirements of ASTM D3261-97.

2. Tensile testing of the butt fused joints prepared from the 20" diameter pipe show that the butt fused area has similar or greater tensile strength compared to the solid (wall) pipe control (samples) and that all failures at the fusion interface are ductile in nature.

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Issued By: J.D. Kim, Ph.D.

Signed: [signature]

Reviewed By: Ken Oliphant, Ph.D., P.Eng.

Signed: [signature]

LICENSED PROFESSIONAL ENGINEER K. E. OLIPHANT PROVINCE OF ONTARIO

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Evaluation and Comparison of Fusion Welds by McElroy McSnapper™ High-Speed Tensile Impact Testing

Objective:

Evaluate and compare joint quality of butt-fused polyethylene pipes molded from Dow's DGDA-2490, Dow's DGDB-2480 and Uponor UAC 2000 in support of the Martin-Marietta Dow Pipeline Project.

Discussion:

In support of a proposed pipeline between Martin-Marietta and Dow facilities to deliver brine solution, a modest study was undertaken to determine the quality and compatibility of fusion and cross-fusion joints made from sections of Dow DGDA-2490 (PE100), Dow DGDB-2480 (PE3408) and Uponor UAC 2000 (PE2406) pipe. Eight-inch diameter, SDR 11 (0.73 inch wall thickness) pipe sections supplied by Quail Piping, Kingman, Arizona (HDPE) and McElroy Manufacturing, Tulsa, Oklahoma (MDPE) were butt-fusion welded by McElroy technical personnel. McElroy's expertise in the fusion of polyethylene pipes is widely recognized. Two interfacial pressures (60 psi and 90 psi) were used to represent a typical range of conditions for butt-welding operations and pipe samples containing fusion welds made at these two different pressures were collected for this study. Four specimens from each joint configuration were fabricated using a McElroy Coupon Cutter. In addition to these samples, coupons were cut from pipe sidewall to serve as controls for this study. The diagram on the last page provides a pictorial representation of these coupons

Heat fusion joining process requires the uniform melting of two opposed (and aligned) surfaces, merging these melted surfaces under pressure and solidifying this merged surface under a given pressure. Uniformity of melting and applied pressure(s) is tantamount to attaining an strong and acceptable fusion that will last the life of the pipe system. Generating a uniform melted surface is the first step in obtaining an acceptable weld. Several factors, such as starting with two smooth parallel pipe surfaces, proper heating temperature, adequate contact time, and uniform pressure on the polymer surface during this melting stage are critical to achieving a uniform melted surface. Polymer factors such as molecular weight, molecular weight distribution, and comonomer content, can effect melting point and the ability of the melt to flow under pressure and temperature. When fusing pipe samples of equivalent polyethylene, the development of a uniform melt surface and resultant interface (fusion) is straight forward and widely practiced art. The fusing of unlike polyethylenes can be a bit more involved and can require an adjustment to the heating/melt portion of the fusion process. For this test, all materials were fused using recognized standard fusion practices.

Samples:

As indicated, examples of butt-fusion welds were collected at each pressure. The high-speed (McSnapper™) tensile impact properties of these welds were compared to sections of wall without a weld present (controls). An important aspect of this testing is to evaluate the fusion compatibility of pipe molded from Dow's new bi-modal HDPE product to itself and with pipe extruded from other existing polyethylene products. For test short examination, two other pipe samples were selected, a PE3408 pipe extruded from Dow's DGDB-2480 and a PE2406 pipe provided by McElroy. The compatibility of Dow DGDA-2490 with other existing pipe materials, namely PE3408 and PE2406 is essential, since on occasion, it may be necessary for a pipe installer to heat fuse pipe components of differing polyethylene materials. Sample descriptions used in this evaluation are provided it the charts that follow

— Chart 1 —

I. Eight-inch Diameter SDR 11 Pipe Sample Descriptions		
II. Designation	III. Resin/Pipe	IV. Pipe Source
V. PE-100	**VI. Dow DGDA-2490**	VII. Quail Piping, Kingman, AZ
VIII. PE3408	**IX. Dow DGDB-2480**	X. Quail Piping, Kingman, AZ
XI. PE2406	**XII. Uponor UAC 2000**	XIII. McElroy Manufacturing, Tulsa, OK

— Chart 2 — Butt-Fusion Sample Descriptions	
Sample Number	**Sample Description**
DW1	PE-100 to PE-100 fused at 60 psi interfacial pressure
DW2	PE-100 to PE-100 fused at 90 psi interfacial pressure
DW3	PE-100 to PE-3408 fused at 60 psi interfacial pressure
DW4	PE-100 to PE-3408 fused at 90 psi interfacial pressure
DW5	PE-100 to PE-2406 fused at 60 psi interfacial pressure
DW6	PE-100 to PE-2406 fused at 90 psi interfacial pressure
DW7	PE-3408 to PE-3408 fused at 60 psi interfacial pressure
DW8	PE-3408 to PE-3408 fused at 90 psi interfacial pressure
DW9	PE-100 no joint (control)
DW10	PE-3408 no joint (control)

Sample Preparation:

For samples DW1 through DW8, sections of pipe wall containing fusion joints at the top, bottom and both sides were removed and cut into coupons by McElroy representatives using a McElroy Coupon Cutter. The specimens containing butt-welds were carefully fabricated to ensure that the fusion joint was located at the center of the specimen. Where dissimilar materials were welded together, each side of the coupon was engraved to indicate the material present on that side of the weld. For the control samples, no fusion was present.

Testing:

The McSnapper™ machine is a tensile with impact testing apparatus, designed specifically for polyolefinic materials. It was developed by McElroy Manufacturing with the expressed intent to accurately test fusion joints. The McSnapper™ combines the tensile impact test ASTM D 1822 and high speed tensile test ASTM D 2289 to provide an accurate test for fused joints by being critical to the fusion, but allowing the pipe to fail if the joint is good. Using the Impact Resistance Test ASTM F 905 as a model, the McSnapper™ is capable of testing sidewall fusions. The machine can also be used in the development of new materials, quality assurance for existing materials, or in fusion compatibility to determine lot uniformity, strength and fuseability of pipe and fittings. While the McSnapper™ test appears to have some usefulness as a quality control test for fusion joints, it only measures one set of "short term" property characteristics of the fusions. As a follow-up to this study, we recognize that testing in accordance with ASTM D-2837, "Standard Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials" should be considered for long-term pressure performance validation of fusion joints.

Results:

All tested specimens were returned along with the data from the McElroy Manufacturing. Since we had the luxury of comparing failed test specimens with the data, we are able to report that no brittle failures were observed in the returned strained coupon specimens. Additionally, all the failures occurred in the pipe sidewall and none occurred at the actual fusion joints. The data from the testing is summarized in chart 3 and chart 4 that follow. In chart 4, the averaged data along with the standard deviation for each of the four individual test specimens run from each fusion joint and control sample. Chart 4 at the end of this document provides all the data generated by McElroy on the pipe fusions and control specimens.

— Chart 3 —

Butt-Fusion McSnapper™ Averaged Results					
Sample		Yield Energy (ft-lbs)	Failure Energy (ft-lbs)	Maximum Force (lbs)	Ultimate Stress (psi)
DW1	avg	19	83	1234	4031
	std dev	1.5	12	21	79
DW2	avg	18	77	1226	4010
	std dev	1.6	3	25	64
DW3	avg	17	67	1172	3908
	std dev	1.0	4	14	39
DW4	avg	17	61	1142	3775
	std dev	1.0	11	31	93
DW5	avg	14	57	1056	3418
	std dev	0.6	5	25	67
DW6	avg	13	57	1055	3459
	std dev	0.5	1	15	43
DW7	avg	19	75	1128	3636
	std dev	2.1	9	18	63
DW8	avg	19	68	1135	3695
	std dev	1.9	8	15	35
DW9	avg	18	87	1201	3964
	std dev	0.8	5	16	60
DW10	avg	19	85	1118	3701
	std dev	1.0	5	40	110

Conclusions, Recommendations and Future Work

Using McElroy's McSnapper™ test apparatus, fusions of like pipes made from Dow 's new PE-100, DGDA-2490 displayed excellent strength compared to control samples without fusions present. Additionally, acceptable fusions of DGDA-2490 with pipes made from standard PE-3408 and PE-2406 materials can be generated using standard butt-fusion techniques. None of the fusion tested displayed brittle failure. All failures were of a ductile nature occurring in the pipe sidewall rather than at the fusion. While these are positive data indicating acceptable joint quality can be achieved using standard fusion techniques with pipe fabrication from Dow PE-100, additional pressure testing will be required to affirm long term pressure validation for field service.

— Chart 4 —

McElroy McSnapper™ Test Results

Sample		Yield Energy (ft-lbs)	Failure Energy (ft-lbs)	Maximum Force (lbs)	Ultimate Stress (psi)
DW1	1	18	72	1206	3915
	2	20	99	1256	4078
	3	21	84	1241	4082
	4	18	78	1231	4049
	avg	**19**	**83**	**1234**	**4031**
	std dev	1.5	12	21	79
DW2	1	16	74	1191	3915
	2	20	76	1226	4030
	3	18	77	1241	4054
	4	18	82	1246	4039
	avg	**18**	**77**	**1226**	**4010**
	std dev	1.6	3	25	64
DW3	1	17	72	1156	3924
	2	16	67	1181	3857
	3	18	66	1186	3948
	4	16	62	1166	3902
	avg	**17**	**67**	**1172**	**3908**
	std dev	1.0	4	14	39
DW4	1	16	44	1105	3647
	2	18	67	1176	3840
	3	16	62	1130	3764
	4	16	69	1156	3848
	avg	**17**	**61**	**1142**	**3775**
	std dev	1.0	11	31	93
DW5	1	13	51	1025	3328
	2	14	61	1085	3478
	3	13	57	1050	3409
	4	14	60	1065	3458
	avg	**14**	**57**	**1056**	**3418**
	std dev	0.6	5	25	67

Sample		Yield Energy (ft-lbs)	Failure Energy (ft-lbs)	Maximum Force (lbs)	Ultimate Stress (psi)
DW6	1	12	58	1040	3467
	2	13	58	1055	3517
	3	13	56	1075	3420
	4	13	56	1050	3433
	avg	**13**	**57**	**1055**	**3459**
	std dev	0.5	1	15	43
DW7	1	17	65	1110	3542
	2	21	71	1120	3665
	3	21	75	1130	3670
	4	18	87	1151	3667
	avg	**19**	**75**	**1128**	**3636**
	std dev	2.1	9	18	63
DW8	1	18	55	1125	3654
	2	20	73	1120	3683
	3	16	70	1145	3737
	4	20	72	1151	3707
	avg	**19**	**68**	**1135**	**3695**
	std dev	1.9	8	15	35
DW9	1	18	92	1181	3882
	2	18	86	1216	3997
	3	19	81	1211	4018
	4	17	90	1196	3958
	avg	**18**	**87**	**1201**	**3964**
	std dev	0.8	5	16	60
DW10	1	18	86	1125	3702
	2	20	77	1065	3575
	3	19	85	1120	3684
	4	18	90	1161	3842
	avg	**19**	**85**	**1118**	**3701**
	std dev	1.0	5	40	110

References:

Jim Perrault, P.E., McElroy Manufacturing, Inc. Testing Report PO#63518814, Dated 4/24/2002

McElroy Manufacturing, Inc. Operator's Manual #S00106 Revised 3/99: "High Speed Tensile with Impact Testing System, McSnapper™"

Plastics Pipe Institute Technical Note, "General Guidelines for Butt, Saddle, and Socket Fusion of Unlike Polyethylene Pipes and Fittings TN-13/2001"

Plastics Pipe Institute Technical Report, "Generic Butt Fusion Joining Procedure for Polyethylene Gas Pipe TR-33/2001"

Uponor Saddle Fusion Test Data with CONTINUUM DGDA-2490 BK 100

Quick Burst Test (ASTM D1599 – 5 specimens)

Sample	Saddle Fusion Tap Tee	Pipe (2" IPS)	Quick Burst Test Results												
			Gauge (psi)	Hoop Stress (psi)	Time (sec)	Failure		S. Fitting #					End Cap		# of Butt Fusion
						Type	Location	1	2	3	4	5	Material	Fusion	
Control	**None**	**DGDC-2480 BK 3408 (1)**	780	3655	70	Ductile	Pipe	---	---	---	---	---	**Solvay K44-08-123**	Butt	2
Control	**None**	**UAC2000 (TR-418)**	600	2895	60	Ductile	Pipe	---	---	---	---	---	**TR418**	Butt	2
A	**DGDA-2490 BK 100**	**DGDC-2480 BK 3408 (1)**	770	3790	69	Ductile	Pipe	OK	OK	OK	OK	OK	**Solvay K44-08-123**	Socket	5
B	**DGDA-2490 BK 100**	**DGDC-2480 BK 3408 (2)**	790	3702	67	Ductile	Pipe	OK	OK	OK	OK	OK	**Solvay K44-08-123**	Butt	5
C	**DGDA-2490 BK 100**	**PE 3408 (AtoFina 3344)**	740	3569	60	Ductile	Pipe	OK	OK	OK	OK	OK	**Solvay K44-08-123**	Socket	5
D	**DGDA-2490 BK 100**	**UAC2000 (TR-418)**	580	2799	64	Ductile	Pipe	OK	OK	OK	OK	OK	**TR418**	Socket	5

Pipe:
DGDC-2480 BK 3408 (1)– lot # T01-051702, 2.373" OD, 0.224" wall, CEC
PE 3408 pipe (Atofina 3344) – lot # T01-051602, 2.374" OD, 0.223" wall, CEC
DGDC-2480 BK 3408 (2) – lot # T07-040303, 2.375" OD, 0.229" wall, CEC
UAC 2000 (TR-418) – lot # T02-060502, 2.375" OD, 0.223" wall, CEC

SF Tap Tee:
CONTINUUM DGDA-2490 BK 100 SF Tap Tee lot # 2003 16755, 2x3/4 IP, 0.500 cutter, CJE CDC
PE 3408 pipe (TR480) SF Tap Tee – lot # 2000 65882, 2x1/2CT, 0.800 cutter,

End Cap:
UAC 2000 (TR 418) SF Cap – lot #200294990, ¾, CEC
PE 3408 (Solvay K44-08-123) – lot # 351332U, ¾ IPS

Uponor Saddle Fusion Data with CONTINUUM DGDA-2490 BK 100

Knock-Out Test (ASTM F905 – 6 specimens) (Hammer weight – 20 lb, Drop height – 14 ft 1 inch)

Sample	Saddle Fusion Tap Tee	Pipe (2" IPS)	S. Fitting #1		S. Fitting #2		S. Fitting #3		S. Fitting #4		S. Fitting #5		S. Fitting #6	
			Fusion Joint	Failure Location	Fusion Joint	Fusion Location	Fusion Joint	Fusion Location	Fusion Joint	Fusion Location	Fusion Joint	Fusion Location	Fusion Joint	Fusion Location
E	**DGDA-2490 BK 100**	**DGDC-2480 BK (1)**	OK	Fitting	OK	Fitting	OK	Fitting	OK	Fitting	OK	Fitting	OK	Fitting
F	**DGDA-2490 BK 100**	**DGDC-2480 BK (2)**	OK	Fitting	OK	Fitting	OK	Fitting	OK	Fitting	OK	Fitting	OK	Fitting
G	**DGDA-2490 BK 100**	**PE 3408 (AtoFina 3344)**	OK	Pipe	OK	Pipe	OK	Pipe	OK	Pipe	OK	Pipe	OK	Pipe
H	**PE 3408 (TR480)**	**DGDC-2480 BK 3408 (1)**	OK	Fitting	OK	Fitting	OK	Fitting	OK	Fitting	OK	Fitting	OK	Fitting
I	**PE 3408 (TR480)**	**DGDC-2480 BK 3408 (2)**	OK	Fitting	OK	Fitting	OK	Fitting	OK	Fitting	OK	Fitting	OK	Fitting

Pipe:
DGDC-2480 BK 3408 (1)– lot # T01-051702, 2.373" OD, 0.224" wall, CEC
PE 3408 pipe (Atofina 3344) – lot # T01-051602, 2.374" OD, 0.223" wall, CEC
DGDC-2480 BK 3408 (2) – lot # T07-040303, 2.375" OD, 0.229" wall, CEC
UAC 2000 (TR-418) – lot # T02-060502, 2.375" OD, 0.223" wall, CEC

SF Tap Tee:
CONTINUUM DGDA-2490 BK 100 SF Tap Tee lot # 2003 16755, 2x3/4 IP, 0.500 cutter, CJE
PE 3408 pipe (TR480) SF Tap Tee – lot # 2000 65882, 2x1/2CT, 0.800 cutter, CDC

End Cap:
UAC 2000 (TR 418) SF Cap – lot #200294990, ¾, CEC
PE 3408 (Solvay K44-08-123) – lot # 351332U, ¾ IPS

APPENDIX D

DATA FOR FITTING QUALIFICATION

Hydrostatic Testing At 80°C and 800 psi of 1" SDR 11 fitting butt-fused to 1" SDR 9 pipe made from CONTINUUM DGDA-2490 material

Injection-Molded Fittings made by Central Plastics
Pipe sample was extruded by the Pipe Technology Center of Dow
Butt-fusion was made by the Pipe Technology Center of Dow
Hydrostatic test was done by PTC of Dow

Fitting			Pipe		Failure	Mode
A-2490	Minimum Thickness (inch)	Diameter (inch)	Minimum Thickness (inch)	Diameter (inch)	Hours	Brittle/Ductile
1	0.120	1.328	0.144	1.312	160	Brittle (pin hole) 180 degrees from the injection molding gate, not at the joint
2	0.120	1.327	0.147	1.315	187	Brittle (pin hole) 180 degrees from the injection molding gate, not at the joint
3	0.119	1.230	0.142	1.312	283	Brittle (pinhole) 180 degrees from the injection molding gate, not at the joint
4	0.117	1.325	0.144	1.310	206	Brittle (pin hole) 180 degrees from the injection molding gate, not at the joint
5	0.119	1.320	0.146	1.311	321	Brittle (pin hole) 180 degrees from the injection molding gate, not at the joint
6	0.111	1.314	0.134	1.310	438	Brittle (pinhole) 180 degrees from the injection molding gate, not at the joint
7	0.113	1.325	0.138	1.309	421	Brittle (pinhole) 180 degrees from the injection molding gate, not at the joint
9	0.111	1.324	0.138	1.311	330	Brittle (pinhole) 180 degrees from the injection molding gate, not at the joint

Hydrostatic Testing At 90°C and 725 psi of 2" SDR 11 fitting butt-fused to 2" SDR 9 pipe made from CONTINUUM DGDA-2490 BK 100

Injection-Molded Fittings made by Central Plastics and Rahn Plastics
Pipe sample was extruded by the Pipe Technology Center of Dow
Butt-fusion was made by the Pipe Technology Center of Dow
Hydrostatic test was done by PTC of Dow

Fittings			Failure	Mode
Rahn Plastics	Minimum Thickness (inch)	Diameter (inch)	Hours	Brittle/Ductile
1	0.225	2.385	2580	**No failures.** All samples removed from testing
2	0.221	2.385	2580	
3	0.216	2.385	2580	
Central Plastics				
4	0.229	2.375	2387	**No failures.** All samples removed from testing
5	0.229	2.375	2111	
6	0.228	2.375	2169	

Perfection's Trials of Mechanical Tapping Tee of Various Sizes Made of CONTINUUM DGDA-2490 BK 100

Injection molded DGDA-2490 BK parts- 1" CTS and 2" IPS
Passed tests specified in ASTM 1598, 1599, F1924, F1588
Hydrostatic Burst Test
Passed @ 80C and 670 psi
Passed @ 23C and 1,000 psi (1,242 hours and test stopped)
Passed the Cone Test

Fusion Joint Test on 2 inch, IPS DGDA-2490 Joined with NCMC Coupling and with M8100 Pipe
Tested @ 80C and 670 psi.
M8100 pipe failed at 1,139 hours
DGDA-2490 did not fail.

APPENDIX E

TECHNICAL REPORTS ON DGDA-2490 PIPES

FROM

OTHER SOURCES

B E C E T E L
BELGIAN RESEARCH CENTRE FOR PIPES AND FITTINGS

REPORT No. 5179

Demanded by	:	DOW CHEMICAL Attn. Mr. J. ZHOU PO&E TS&D, Rm110/B98 171 River Road PISCATAWAY, NJ 08854 U.S.A.
At the expense of	:	idem
Concerning	:	Determination of the resistance to rapid crack propagation of 10" PE pipes (S4 test method), product DGDA-2490 BK 100. Your order by e-mail dd. 26/06/2001.
Our reference	:	BEC 3616 and SR010333.doc
Our invoice no.	:	no. 20010511
Date of the report	:	27 September 2001
This report contains	:	4 pages

General remark

The results mentioned in this report are exclusively related to the product as defined hereinafter and this document may, in no case, be considered as an approval of this product.
To warrant that the results would be representative of the product, as it is delivered or applied, conformity of the specimens to the product should be assured.
The specimens are at your disposal during two months after the date of the report.
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DETERMINATION OF THE RESISTANCE TO RAPID CRACK PROPAGATION OF 10" PE PIPES (S4 TEST METHOD), PRODUCT DGDA-2490 BK 100

1 Received material

10 PE pipes 10", delivered to Becetel on 20 July 2001.

Product name:	DGDA-2490 BK 100
Marking:	PLEXCO EHWW 10" IPS D11 PE3408 ASTM F714 C3 U-401 A002 06/25/01
Colour:	black
Length:	2,0 m
Pipe dimensions:	diameter 273 mm, wall thickness 25 mm

The pipes are extruded and delivered to Becetel by Plexco Inc. (USA).

2 Test program

The tests on the PE pipes are executed in accordance with ISO 13477 "Thermoplastics pipes for the conveyance of fluids - Determination of the resistance to Rapid Crack Propagation (RCP) - Small-Scale Steady-State Test (S4 test)"

The critical pressure at a temperature of 0 °C is determined, followed by a measurement of critical temperature at a pressure of 10 bar.
The critical pressure is determined again, but at that temperature where crack propagation occurs at 10 bar pressure.

3 Principle

The Small-Scale Steady State (S4) test is developed to determine the critical pressure of plastics pipes, i.e. the minimum internal pressure which results in a propagation of the brittle fracture over the entire length of the test piece.
The S4 test simulates a steady state propagation of the rapid crack by an artificial limitation of decompression of the pipe during the crack propagation. The decompression ahead of the propagating crack is retarded by internal baffles and by an external containment cage, which restricts flaring of the pipe at the edges of the fracture.
Hence the stress at the crack tip does not decrease and the propagation of the crack is sustained.
The fast-running axial crack is initiated by driving a knife in the pipe wall, near one end, at a considerable speed (15 ± 5 m/s).
Tests are executed at different internal pressures in order to determine the transition from crack arrest to crack propagation over the entire length of the specimen. This transition defines the critical pressure of the pipe material, $p_{c,S4}$.

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BTW/TVA/VAT : BE 406 633 106 – FORTIS BANK GENT 290-0083433-34 – KBC GENT 447-0039971-29
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4 Test conditions

- External diameter of the pipes d_n: 270 mm;
- Wall thickness e_n: 25 mm;
- Length of the pipes: 1800 mm;
- Propagation zone: 1270 mm;
- Number of pressure chambers: 10;
- Internal diameter of the containment cage: 300 mm;
- The crack length is measured following the pipe axis (= projection of the crack path onto the pipe axis);
- Test temperatures: see below, obtained by conditioning the test pipes in a freezer;
- The test pressures are reached using compressed air;
- Impact velocity: 12 m/s;
- Test date: 4-14 September 2001.

5 Test results

The crack lengths in the following tables are measured from the center of the knife impact. The crack lengths are also given in relation to the nominal diameter of the pipes d_n.

Pipe no.	Temperature °C	Internal pressure (bar)	Crack length a (mm)	a/d_n	Results
1	0	5,0	475	1,8	Crack arrest
2	0	10,0	375	1,4	Crack arrest
3	0	11,5	405	1,5	Crack arrest
4	-10	10,0	855	3,2	Crack arrest
5	-15	10,0	720	2,7	Crack arrest
6	-17	10,0	865	3,2	Crack arrest
7	-20	1,5	270	1,0	Crack arrest
8	-20	2,0	1430	5,3	Crack propagation
9	-20	3,0	1430	5,3	Crack propagation
10	-20	10,0	1430	5,3	Crack propagation

Due to the lack of test pieces, no more tests at –20°C could be performed for a more precise determination of the critical pressure.

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6 Discussion of results

The S4 tests on the 10 " PE pipes, product DGDA-2490 BK 100 at a temperature of 0 °C. result in a critical pressure $p_{c,S4}$ of higher than 11,5 bar.
The critical temperature $T_{c,S4}$ at 10 bar air pressure is determined at −17°C. The critical pressure $p_{c,S4}$ at −20°C is determined at 1,5 bar.

Melle, 27 September 2001.

ir. J. VIENNE
Staff Member

Prof. ir. P. VANSPEYBROECK
General Director

BECETEL VZW / ASBL
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uponor

TECHNICAL LAB REPORT

Uponor Aldyl Company
4501 West 49th Street
Tulsa, OK 74107-7315
Tel. (918) 446-4471
Fax (918) 446-9369

Plant Contact: Larry Shelton - Phone 918-445-5643
Job Number: 090301 Lot Number: Pipe – T01081303 / Ftgs. –200316754 & 200316755.

Background: Uponor produced UAC 3700 ULTRA-STRIPE pipe and UAC 3700 molded fittings from Dow A 2490 PE 100 resin. The pipe and fittings were joined to each other and other PE 3408 pipe products. The heat fusion joints were qualified per DOT 192.283 requirements.

Product Description: Uponor UAC 3700 2 X ¾" butt outlet tap tees, UAC 3700 couplings, and UAC 3700 pipe produced from Dow DGDA 2490 PE 100 / PE 3408 resin.

Scope: Testing was performed to qualify the extrusion process of UAC 3700 pipe from Dow DGDA 2490 PE 100/PE 3408 resin and to qualify the heat fusion joints between Uponor UAC 3700 pipe and fittings to other PE3408 pipe products.

Preparation: **Test Conditions: 23° C & 80° C**
Test Procedures: Per ASTM F 905, ASTM D 638, ASTM D 1598, & ASTM D 1599.
ASTM D 1599: 15 specimens were tested, with ductile failure occurring in the pipe wall.
ASTM F 905 18 specimens were tested, with all failures occurring in the pipe wall.
ASTM D 638: 36 specimens were elongated > 25% with no joint failures.
ASTM D 1598 12 specimens were squeezed per D 2513, A1.5.5, then tested > 1000 hrs with no failures.
Conclusion: **All specimens met or exceeded the listed procedure requirements, thereby meeting the qualification requirements per ASTM D 2513 & DOT 192.283. See attached data.**

Note: "We certify that all portions of each test performed were under continuous, direct supervision of this laboratory."

Bob Creason | Larry Shelton

Bob Creason
Lab Operator

Larry Shelton
Lab Supervisor

UAC 3700/Dow A 2490 Resin 2" Pipe Samples

Lot Number T01081303 / 2" IPS SDR 11 UAC 3700 Pipe
Resin lot # QE1755P83B, Masterbatch # 241120308
All D 1598 specimens squeezed-off per D 2513, A1.5.5 requirements

Sustained Pressure Test per ASTM D 1598

Sample	Test Temp	Stress	Time	Results
1	80° C	670 psi	>1000 hrs	Passed
2	80° C	670 psi	>1000 hrs	Passed
3	80° C	670 psi	>1000 hrs	Passed
4	80° C	670 psi	>1000 hrs	Passed
5	80° C	670 psi	>1000 hrs	Passed
6	80° C	670 psi	>1000 hrs	Passed

Sustained Pressure Test per ASTM D 1598

Sample	Test Temp	Stress	Time	Results
1	23° C	1600 psi	>1000 hrs	Passed
2	23° C	1600 psi	>1000 hrs	Passed
3	23° C	1600 psi	>1000 hrs	Passed
4	23° C	1600 psi	>1000 hrs	Passed
5	23° C	1600 psi	>1000 hrs	Passed
6	23° C	1600 psi	>1000 hrs	Passed

Quick Burst Test per ASTM D 1599

Sample	Test Temp	Stress	Time	Mode	Result
1	23° C	740 psig	68 Sec	Ductile	Passed

ASTM D 2513 Dimension Specifications for 2" SDR 11 Pipe
Wall: .216" - .242" / OD: 2.369" - 2.381"
As Measured Dimensions

Sample	Wall	OD
1	.225 - .229	2.379
2	.221 - .225	2.380
3	.224 - .229	2.380
4	.224 - .229	2.380
5	.222 - .226	2.380
6	.222 - .226	2.380

YELLOWSTRIPE 8300 PIPE TO UAC 3700 TAP TEE SADDLE FUSION PROCEDURE QUALIFICATION PER D.O.T. 192.283

SHORT-TERM BURST TEST (ASTM D1599)
Fusion Parameters: Fused at 500°F per Uponor fusion procedures.

Test Specimen	Failure Mode	Time to Failure (seconds)	Failure Pressure (PSIG)
Sample #1	In Pipe, Ductile	63	740
Sample #2	In Pipe, Ductile	63	740
Sample #3	In Pipe, Ductile	63	740
Sample #4	In Pipe, Ductile	64	750
Sample #5	In Pipe, Ductile	64	750
Sample #6	In Pipe, Ductile	64	750

IMPACT RESISTANCE PER (ASTM F905)

Test Specimen	Result
Sample #1	Pipe wall torn out/**pass**
Sample #2	Pipe wall torn out/**pass**
Sample #3	Pipe wall torn out/**pass**
Sample #4	Pipe wall torn out/**pass**
Sample #5	Pipe wall torn out/**pass**
Sample #6	Pipe wall torn out/**pass**

UAC 3700 PIPE TO DRISCOPIPE 8100 PIPE BUTT FUSION PROCEDURE QUALIFICATION PER D.O.T. 192.283

SHORT-TERM BURST TEST (ASTM D1599)
Fusion Parameters: Fused at 500°F per Uponor fusion procedures.

Test Specimen	Failure Mode	Time to Failure (seconds)	Failure Pressure (PSIG)
Sample A	In Pipe, Ductile	64	740
Sample B	In Pipe, Ductile	64	740
Sample C	In Pipe, Ductile	64	740

TENSILE ELONGATION (ASTM D638)

Test Specimen	%Elongation	Result
Sample #1	>50%	No Joint Failure
Sample #2	>50%	No Joint Failure
Sample #3	>50%	No Joint Failure

SHORT-TERM BURST TEST (ASTM D1599)
Fusion Parameters: Fused at 400°F - 450°F per PPI Generic fusion procedures.

Test Specimen	Failure Mode	Time to Failure (seconds)	Failure Pressure (PSIG)
Sample D	In Pipe, Ductile	65	730
Sample E	In Pipe, Ductile	65	730
Sample F	In Pipe, Ductile	65	730

TENSILE ELONGATION (ASTM D638)

Test Specimen	%Elongation	Result
Sample #4	>50%	No Joint Failure
Sample #5	>50%	No Joint Failure
Sample #6	>50%	No Joint Failure

UAC 3700 PIPE TO UAC 3700 PIPE BUTT FUSION PROCEDURE QUALIFICATION PER D.O.T. 192.283

SHORT-TERM BURST TEST (ASTM D1599)
Fusion Parameters: Fused at 500°F per Uponor fusion procedures.

Test Specimen	Failure Mode	Time to Failure (seconds)	Failure Pressure (PSIG)
Sample A	In Pipe, Ductile	64	740
Sample B	In Pipe, Ductile	64	740
Sample C	In Pipe, Ductile	64	740

TENSILE ELONGATION (ASTM D638)

Test Specimen	%Elongation	Result
Sample #1	>50%	No Joint Failure
Sample #2	>50%	No Joint Failure
Sample #3	>50%	No Joint Failure

SHORT-TERM BURST TEST (ASTM D1599)
Fusion Parameters: Fused at 400°F - 450°F per PPI Generic fusion procedures.

Test Specimen	Failure Mode	Time to Failure (seconds)	Failure Pressure (PSIG)
Sample D	In Pipe, Ductile	65	730
Sample E	In Pipe, Ductile	65	730
Sample F	In Pipe, Ductile	65	730

TENSILE ELONGATION (ASTM D638)

Test Specimen	%Elongation	Result
Sample #4	>50%	No Joint Failure
Sample #5	>50%	No Joint Failure
Sample #6	>50%	No Joint Failure

UAC 3700 PIPE TO UAC 3700 SOCKET COUPLING PROCEDURE QUALIFICATION PER D.O.T. 192.283

SHORT-TERM BURST TEST (ASTM D1599)

Fusion Parameters: Fused at 500°F per Uponor fusion procedures.

Test Specimen	Failure Mode	Time to Failure (seconds)	Failure Pressure (PSIG)
Sample #1	In Pipe, Ductile	66	760
Sample #2	In Pipe, Ductile	66	760
Sample #3	In Pipe, Ductile	66	760
Sample #4	In Pipe, Ductile	66	760
Sample #5	In Pipe, Ductile	66	760
Sample #6	In Pipe, Ductile	66	760

TENSILE ELONGATION (ASTM D638)

Test Specimen	%Elongation	Result
Sample #1	>50%	No Joint Failure
Sample #2	>50%	No Joint Failure
Sample #3	>50%	No Joint Failure
Sample #4	>50%	No Joint Failure
Sample #5	>50%	No Joint Failure
Sample #6	>50%	No Joint Failure

UAC 3700 PIPE TO UAC 3700 TAP TEE SADDLE FUSION PROCEDURE QUALIFICATION PER D.O.T. 192.283

SHORT-TERM BURST TEST (ASTM D1599)
Fusion Parameters: Fused at 500°F per Uponor fusion procedures.

Test Specimen	Failure Mode	Time to Failure (seconds)	Failure Pressure (PSIG)
Sample #1	In Pipe, Ductile	68	740
Sample #2	In Pipe, Ductile	68	740
Sample #3	In Pipe, Ductile	68	740
Sample #4	In Pipe, Ductile	68	740
Sample #5	In Pipe, Ductile	68	740
Sample #6	In Pipe, Ductile	68	740

IMPACT RESISTANCE PER (ASTM F905)

Test Specimen	Result
Sample #1	Pipe wall torn out/**pass**
Sample #2	Pipe wall torn out/**pass**
Sample #3	Pipe wall torn out/**pass**
Sample #4	Pipe wall torn out/**pass**
Sample #5	Pipe wall torn out/**pass**
Sample #6	Pipe wall torn out/**pass**

DRISCOPIPE 8100 PIPE to UAC 3700 SOCKET COUPLING PROCEDURE QUALIFICATION PER D.O.T. 192.283

SHORT-TERM BURST TEST (ASTM D1599)
Fusion Parameters: Fused at 500°F per Uponor fusion procedures.

Test Specimen	Failure Mode	Time to Failure (seconds)	Failure Pressure (PSIG)
Sample #1	In Pipe, Ductile	66	760
Sample #2	In Pipe, Ductile	66	760
Sample #3	In Pipe, Ductile	66	760
Sample #4	In Pipe, Ductile	66	760
Sample #5	In Pipe, Ductile	66	760
Sample #6	In Pipe, Ductile	66	760

TENSILE ELONGATION (ASTM D638)

Test Specimen	%Elongation	Result
Sample #1	>50%	No Joint Failure
Sample #2	>50%	No Joint Failure
Sample #3	>50%	No Joint Failure
Sample #4	>50%	No Joint Failure
Sample #5	>50%	No Joint Failure
Sample #6	>50%	No Joint Failure

DRISCOPIPE 8100 PIPE TO UAC 3700 TAP TEE SADDLE FUSION PROCEDURE QUALIFICATION PER D.O.T. 192.283

SHORT-TERM BURST TEST (ASTM D1599)
Fusion Parameters: Fused at 500°F per Uponor fusion procedures.

Test Specimen	Failure Mode	Time to Failure (seconds)	Failure Pressure (PSIG)
Sample #1	In Pipe, Ductile	63	800
Sample #2	In Pipe, Ductile	63	800
Sample #3	In Pipe, Ductile	63	800
Sample #4	In Pipe, Ductile	64	810
Sample #5	In Pipe, Ductile	64	810
Sample #6	In Pipe, Ductile	64	810

IMPACT RESISTANCE PER (ASTM F905)

Test Specimen	Result
Sample #1	Pipe wall torn out/**pass**
Sample #2	Pipe wall torn out/**pass**
Sample #3	Pipe wall torn out/**pass**
Sample #4	Pipe wall torn out/**pass**
Sample #5	Pipe wall torn out/**pass**
Sample #6	Pipe wall torn out/**pass**

YELLOWSTRIPE 8300 PIPE TO UAC 3700 TAP TEE SADDLE FUSION PROCEDURE QUALIFICATION PER D.O.T. 192.283

SHORT-TERM BURST TEST (ASTM D1599)
Fusion Parameters: Fused at 500°F per Uponor fusion procedures.

Test Specimen	Failure Mode	Time to Failure (seconds)	Failure Pressure (PSIG)
Sample #1	In Pipe, Ductile	63	740
Sample #2	In Pipe, Ductile	63	740
Sample #3	In Pipe, Ductile	63	740
Sample #4	In Pipe, Ductile	64	750
Sample #5	In Pipe, Ductile	64	750
Sample #6	In Pipe, Ductile	64	750

IMPACT RESISTANCE PER (ASTM F905)

Test Specimen	Result
Sample #1	Pipe wall torn out/**pass**
Sample #2	Pipe wall torn out/**pass**
Sample #3	Pipe wall torn out/**pass**
Sample #4	Pipe wall torn out/**pass**
Sample #5	Pipe wall torn out/**pass**
Sample #6	Pipe wall torn out/**pass**

YELLOWSTRIPE 8300 PIPE to UAC 3700 SOCKET COUPLING PROCEDURE QUALIFICATION PER D.O.T. 192.283

SHORT-TERM BURST TEST (ASTM D1599)

Fusion Parameters: Fused at 500°F per Uponor fusion procedures.

Test Specimen	Failure Mode	Time to Failure (seconds)	Failure Pressure (PSIG)
Sample #1	In Pipe, Ductile	66	750
Sample #2	In Pipe, Ductile	66	750
Sample #3	In Pipe, Ductile	66	750
Sample #4	In Pipe, Ductile	66	750
Sample #5	In Pipe, Ductile	66	750
Sample #6	In Pipe, Ductile	66	750

TENSILE ELONGATION (ASTM D638)

Test Specimen	%Elongation	Result
Sample #1	>50%	No Joint Failure
Sample #2	>50%	No Joint Failure
Sample #3	>50%	No Joint Failure
Sample #4	>50%	No Joint Failure
Sample #5	>50%	No Joint Failure
Sample #6	>50%	No Joint Failure

UAC 3700 PIPE TO YELLOWSTRIPE 8300 PIPE BUTT FUSION PROCEDURE QUALIFICATION PER D.O.T. 192.283

SHORT-TERM BURST TEST (ASTM D1599)
Fusion Parameters: Fused at 500°F per Uponor fusion procedures.

Test Specimen	Failure Mode	Time to Failure (seconds)	Failure Pressure (PSIG)
Sample A	In Pipe, Ductile	64	740
Sample B	In Pipe, Ductile	64	740
Sample C	In Pipe, Ductile	64	740

TENSILE ELONGATION (ASTM D638)

Test Specimen	%Elongation	Result
Sample #1	>50%	No Joint Failure
Sample #2	>50%	No Joint Failure
Sample #3	>50%	No Joint Failure

SHORT-TERM BURST TEST (ASTM D1599)
Fusion Parameters: Fused at 400°F - 450°F per PPI Generic fusion procedures.

Test Specimen	Failure Mode	Time to Failure (seconds)	Failure Pressure (PSIG)
Sample D	In Pipe, Ductile	65	750
Sample E	In Pipe, Ductile	65	750
Sample F	In Pipe, Ductile	65	750

TENSILE ELONGATION (ASTM D638)

Test Specimen	%Elongation	Result
Sample #4	>50%	No Joint Failure
Sample #5	>50%	No Joint Failure
Sample #6	>50%	No Joint Failure

Evaluation and Comparison of Fusion Welds by McElroy McSnapper™ High-Speed Tensile Impact Testing

Objective:

Evaluate and compare joint quality of butt-fused polyethylene pipes molded from Dow's DGDA-2490, Dow's DGDB-2480 and Uponor UAC 2000 in support of the Martin-Marietta Dow Pipeline Project.

Discussion:

In support of a proposed pipeline between Martin-Marietta and Dow facilities to deliver brine solution, a modest study was undertaken to determine the quality and compatibility of fusion and cross-fusion joints made from sections of Dow DGDA-2490 (PE100), Dow DGDB-2480 (PE3408) and Uponor UAC 2000 (PE2406) pipe. Eight-inch diameter, SDR 11 (0.73 inch wall thickness) pipe sections supplied by Quail Piping, Kingman, Arizona (HDPE) and McElroy Manufacturing, Tulsa, Oklahoma (MDPE) were butt-fusion welded by McElroy technical personnel. McElroy's expertise in the fusion of polyethylene pipes is widely recognized. Two interfacial pressures (60 psi and 90 psi) were used to represent a typical range of conditions for butt-welding operations and pipe samples containing fusion welds made at these two different pressures were collected for this study. Four specimens from each joint configuration were fabricated using a McElroy Coupon Cutter. In addition to these samples, coupons were cut from pipe sidewall to serve as controls for this study. The diagram on the last page provides a pictorial representation of these coupons

Heat fusion joining process requires the uniform melting of two opposed (and aligned) surfaces, merging these melted surfaces under pressure and solidifying this merged surface under a given pressure. Uniformity of melting and applied pressure(s) is tantamount to attaining an strong and acceptable fusion that will last the life of the pipe system. Generating a uniform melted surface is the first step in obtaining an acceptable weld. Several factors, such as starting with two smooth parallel pipe surfaces, proper heating temperature, adequate contact time, and uniform pressure on the polymer surface during this melting stage are critical to achieving a uniform melted surface. Polymer factors such as molecular weight, molecular weight distribution, and comonomer content, can effect melting point and the ability of the melt to flow under pressure and temperature. When fusing pipe samples of equivalent polyethylene, the development of a uniform melt surface and resultant interface (fusion) is straight forward and widely practiced art. The fusing of unlike polyethylenes can be a bit more involved and can require an adjustment to the heating/melt portion of the fusion process. For this test, all materials were fused using recognized standard fusion practices.

Samples:

As indicated, examples of butt-fusion welds were collected at each pressure. The high-speed (McSnapper™) tensile impact properties of these welds were compared to sections of wall without a weld present (controls). An important aspect of this testing is to evaluate the fusion compatibility of pipe molded from Dow's new bi-modal HDPE product to itself and with pipe extruded from other existing polyethylene products. For test short examination, two other pipe samples were selected, a PE3408 pipe extruded from Dow's DGDB-2480 and a PE2406 pipe provided by McElroy. The compatibility of Dow DGDA-2490 with other existing pipe materials, namely PE3408 and PE2406 is essential, since on occasion, it may be necessary for a pipe installer to heat fuse pipe components of differing polyethylene materials. Sample descriptions used in this evaluation are provided it the charts that follow

— Chart 1 —

Eight-inch Diameter SDR 11 Pipe Sample Descriptions		
Designation	**Resin/Pipe**	**Pipe Source**
PE-100	Dow DGDA-2490	**Quail Piping, Kingman, AZ**
PE3408	Dow DGDB-2480	**Quail Piping, Kingman, AZ**
PE2406	Uponor UAC 2000	**McElroy Manufacturing, Tulsa, OK**

— chart 2 — **Butt-Fusion Sample Descriptions**	
Sample Number	**Sample Description**
DW1	PE-100 to PE-100 fused at 60 psi interfacial pressure
DW2	PE-100 to PE-100 fused at 90 psi interfacial pressure
DW3	PE-100 to PE-3408 fused at 60 psi interfacial pressure
DW4	PE-100 to PE-3408 fused at 90 psi interfacial pressure
DW5	PE-100 to PE-2406 fused at 60 psi interfacial pressure
DW6	PE-100 to PE-2406 fused at 90 psi interfacial pressure
DW7	PE-3408 to PE-3408 fused at 60 psi interfacial pressure
DW8	PE-3408 to PE-3408 fused at 90 psi interfacial pressure
DW9	PE-100 no joint (control)
DW10	PE-3408 no joint (control)

Sample Preparation:

For samples DW1 through DW8, sections of pipe wall containing fusion joints at the top, bottom and both sides were removed and cut into coupons by McElroy representatives using a McElroy Coupon Cutter. The specimens containing butt-welds were carefully fabricated to ensure that the fusion joint was located at the center of the specimen.

Where dissimilar materials were welded together, each side of the coupon was engraved to indicate the material present on that side of the weld. For the control samples, no fusion was present.

Testing:

The McSnapper™ machine is a tensile with impact testing apparatus, designed specifically for polyolefinic materials. It was developed by McElroy Manufacturing with the expressed intent to accurately test fusion joints. The McSnapper™ combines the tensile impact test ASTM D 1822 and high speed tensile test ASTM D 2289 to provide an accurate test for fused joints by being critical to the fusion, but allowing the pipe to fail if the joint is good. Using the Impact Resistance Test ASTM F 905 as a model, the McSnapper™ is capable of testing sidewall fusions. The machine can also be used in the development of new materials, quality assurance for existing materials, or in fusion compatibility to determine lot uniformity, strength and fuseability of pipe and fittings. While the McSnapper™ test appears to have some usefulness as a quality control test for fusion joints, it only measures one set of "short term" property characteristics of the fusions. As a follow-up to this study, we recognize that testing in accordance with ASTM D-2837, "Standard Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials" should be considered for long-term pressure performance validation of fusion joints.

Results:

All tested specimens were returned along with the data from the McElroy Manufacturing. Since we had the luxury of comparing failed test specimens with the data, we are able to report that no brittle failures were observed in the returned strained coupon specimens. Additionally, all the failures occurred in the pipe sidewall and none occurred at the actual fusion joints. The data from the testing is summarized in chart 3 and chart 4 that follow. In chart 4, the averaged data along with the standard deviation for each of the four individual test specimens run from each fusion joint and control sample. Chart 4 at the end of this document provides all the data generated by McElroy on the pipe fusions and control specimens.

— chart 3 —

Butt-Fusion McSnapper™ Averaged Results					
Sample		Yield Energy (ft-lbs)	Failure Energy (ft-lbs)	Maximum Force (lbs)	Ultimate Stress (psi)
DW 1	avg	**19**	**83**	**1234**	**4031**
	std dev	1.5	12	21	79
DW 2	avg	**18**	**77**	**1226**	**4010**
	std dev	1.6	3	25	64
DW 3	avg	**17**	**67**	**1172**	**3908**
	std dev	1.0	4	14	39
DW 4	avg	**17**	**61**	**1142**	**3775**
	std dev	1.0	11	31	93
DW 5	avg	**14**	**57**	**1056**	**3418**
	std dev	0.6	5	25	67
DW 6	avg	**13**	**57**	**1055**	**3459**
	std dev	0.5	1	15	43
DW 7	avg	**19**	**75**	**1128**	**3636**
	std dev	2.1	9	18	63
DW 8	avg	**19**	**68**	**1135**	**3695**
	std dev	1.9	8	15	35
DW 9	avg	**18**	**87**	**1201**	**3964**
	std dev	0.8	5	16	60
DW 10	avg	**19**	**85**	**1118**	**3701**
	std dev	1.0	5	40	110

Conclusions, Recommendations and Future Work:

Using McElroy's McSnapper™ test apparatus, fusions of like pipes made from Dow 's new PE-100, DGDA-2490 displayed excellent strength compared to control samples without fusions present. Additionally, acceptable fusions of DGDA-2490 with pipes made from standard PE-3408 and PE-2406 materials can be generated using standard butt-fusion techniques. None of the fusion tested displayed brittle failure. All failures were of a ductile nature occurring in the pipe sidewall rather than at the fusion. While these are positive data indicating acceptable joint quality can be achieved using standard fusion techniques with pipe fabrication from Dow PE-100, additional pressure testing will be required to affirm long term pressure validation for field service.

— chart 4 —

McElroy McSnapper™ Test Results

Sample		Yield Energy (ft-lbs)	Failure Energy (ft-lbs)	Maximum Force (lbs)	Ultimate Stress (psi)	Sample		Yield Energy (ft-lbs)	Failure Energy (ft-lbs)	Maximum Force (lbs)	Ultimate Stress (psi)
DW 1	1	18	72	1206	3915	DW 6	1	12	58	1040	3467
	2	20	99	1256	4078		2	13	58	1055	3517
	3	21	84	1241	4082		3	13	56	1075	3420
	4	18	78	1231	4049		4	13	56	1050	3433
	avg	**19**	**83**	**1234**	**4031**		avg	**13**	**57**	**1055**	**3459**
	std dev	1.5	12	21	79		std dev	0.5	1	15	43
DW 2	1	16	74	1191	3915	DW 7	1	17	65	1110	3542
	2	20	76	1226	4030		2	21	71	1120	3665
	3	18	77	1241	4054		3	21	75	1130	3670
	4	18	82	1246	4039		4	18	87	1151	3667
	avg	**18**	**77**	**1226**	**4010**		avg	**19**	**75**	**1128**	**3636**
	std dev	1.6	3	25	64		std dev	2.1	9	18	63
DW 3	1	17	72	1156	3924	DW 8	1	18	55	1125	3654
	2	16	67	1181	3857		2	20	73	1120	3683
	3	18	66	1186	3948		3	16	70	1145	3737
	4	16	62	1166	3902		4	20	72	1151	3707
	avg	**17**	**67**	**1172**	**3908**		avg	**19**	**68**	**1135**	**3695**
	std dev	1.0	4	14	39		std dev	1.9	8	15	35
DW 4	1	16	44	1105	3647	DW 9	1	18	92	1181	3882
	2	18	67	1176	3840		2	18	86	1216	3997
	3	16	62	1130	3764		3	19	81	1211	4018
	4	16	69	1156	3848		4	17	90	1196	3958
	avg	**17**	**61**	**1142**	**3775**		avg	**18**	**87**	**1201**	**3964**
	std dev	1.0	11	31	93		std dev	0.8	5	16	60
DW 5	1	13	51	1025	3328	DW 10	1	18	86	1125	3702
	2	14	61	1085	3478		2	20	77	1065	3575
	3	13	57	1050	3409		3	19	85	1120	3684
	4	14	60	1065	3458		4	18	90	1161	3842
	avg	**14**	**57**	**1056**	**3418**		avg	**19**	**85**	**1118**	**3701**
	std dev	0.6	5	25	67		std dev	1.0	5	40	110

David W. Kababik / April 24, 2002

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New Products, New Horizons: High Density Polyethylene (HDPE) Resins for Natural Gas Piping

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ABSTRACT

Three polyethylene (PE) gas pipe materials used in the United States are analyzed. They include two unimodal medium density polyethylene (MDPE) PE2406 with 1000 psi and 800 psi hydrostatic design basis (HDB) at 60°C respectively, and one unimodal high density polyethylene (HDPE) PE3408 with 800 psi HDB at 60°C. Recent progress in PE bimodal technology have led to three new HDPE pipe materials: enhanced PE3408 having 1000 psi HDB at 60°C; conventional PE100 having a minimum required strength (MRS) listing at 20°C; and enhanced PE100 having MRS listings at both 20°C and elevated temperatures. This paper will compare the key properties of these materials that determine the long-term performances of a gas pipe system. It will focus on pressure capability at room and elevated temperatures, resistance to slow crack growth (SCG), resistance to rapid crack propagation (RCP), and quality of butt-fusion joints of same pipe and hybrid welds of different pipes.

For HDB-rated materials, the enhanced PE3408 bimodal HDPE pipe provides higher-pressure capability at a broad temperature range, improved SCG and RCP resistance, and enhanced joining quality. The PE100 pipe materials deliver the same, or better, properties than PE3408 bimodal HDPE material and performs better than the unimodal pipe materials. In addition, PE100 materials offer higher-pressure capability around room temperatures. In particular, the enhanced PE100 material offers higher-pressure capability in the temperature range up to 60°C than both PE2406 and PE3408.

INTRODUCTION

Pipeline operation pressure is important for gas utilities to ensure the efficient transportation and distribution of natural gases. Therefore it is desirable to use materials with high pressure ratings. In service, the ambient temperatures of a natural gas pipeline can significantly vary from place to place and/or from daytime to nighttime. Because of this, pressure ratings of pipe materials at elevated temperatures that cover the maximum ambient temperatures are necessary to properly design and safely operate the pipeline system. ASTM D2837 [(1)] and ISO 9080 [(2)] can be used to extrapolate the long-term hydrostatic strength (LTHS) to 11 and 50 years, respectively, for pressure rating purposes. Plastic Pipe Institute (PPI) lists both HDB and MRS in TR-4 [(3)]. If operated properly and below the pressure rating, a pipeline will not fail in the ductile failure mode.

Pipelines can fail in other modes other than ductile failures after long time service. Steel pipe, for instance, can leak due to corrosion. PE pipe is virtually corrosion-free, offering a major advantage over metal pipe. Pipe can also fail long-term in a brittle manner through slow crack growth (SCG) failure mode. SCG is the main failure mode of a PE gas pipeline. It is believed that the resistance to SCG, as measured by PENT test [(4)], ASTM F1473, is related to the failure rate of a pipeline in the field. The longer the PENT lifetime, the lower the failure rate and the safer the pipeline is against leakage. SCG failures usually cause a small leak on a local basis for an individual pipe within the pipeline system.

In gas pressure pipe, a large amount of energy is stored in the pipeline infrastructure because of internal operating pressure. Rapid crack propagation (RCP) can occur under the driving force of this stored energy. RCP failure is rare but catastrophic. It can destroy hundreds of meters of pipelines within seconds. Unlike local and individual SCG failures, RCP failures can result in an explosion, destroying an entire pipeline system on a very large scale.

Resin producers have made significant progress in the past several years, developing a new generation of HDPE resins, via bimodal technology, for natural gas application that delivers safer and higher performing PE pipe material. This new bimodal technology is an improvement over the conventional unimodal technology. These new materials have higher-pressure ratings for a broader temperature range and resistance to SCG and RCP is significantly improved.

This paper will investigate three groups of gas pipe grade materials of PE2406, PE3408 and PE100 and compare the new bimodal HDPE materials with conventional medium and high density unimodal PE pipe materials currently used in North America.

PIPE MATERIALS INVESTIGATED

Three groups of gas pipe samples are shown in the comparison study in Table 1. PE2406 and PE3408 meet the requirements of ASTM D2513[5] for gas pipe application. PE100 pipe meets ISO 4437 [6] for gas pipe applications. They all have more than 100 h PENT for SCG. In addition, they have either a CDC or CEC rating [5] in accordance to D2513 for the gas pipe category. In naming the different samples below, the letter C represents conventional products, letter S represents standard products, and letter E is for the enhanced pipe products.

Table 1. Material Designation of the PE Pipe Materials

Samples	Material Designation			
	ASTM D3350[7], PPI TR-4	ASTM D2513	ISO 9080 ISO12162[8]	ASTM D3350
	Pipe Grade	Pipe Category	Pipe Grade	Cell Classification
PE2406C	PE2406	CDC		234363A
PE2406S	PE2406	CEC		234363A
PE3408S	PE3408	CDC		345464C
PE3408E	PE3408	CEC		346564C
PE100S	PE3408	CEC	PE100	345566C
PE100E	PE3408	CEC	PE100	346566C

Table 2 General Characterization of the PE Pipe Materials

Property	PE2406		PE3408		PE100	
	C	S	S	E	S	E
Technology	Gas Phase	Slurry	Gas Phase	Gas Phase	Slurry	Gas Phase
Molecular Structure	Unimodal	Unimodal	Unimodal	Bimodal	Bimodal	Bimodal
Melt Index, I_2	0.2	0.2	0.1	0.08	0.1	0.08
Flow Index, I_{21}	18	20	8.3	9	6.8	9
Resin Density	0.939	0.940	0.944	0.949	0.951	0.949
Flexural Modulus, psi	100,000	100,000	126,000	165,000	140,000	165,000
Tensile Strength at Yield, psi	2,800	2,800	3,200	3,600	3,700	3,600

The general characterization of the pipe materials is illustrated in Table 2. PE3408E, PE100S and PE100E are bimodal HDPE materials. MDPE PE2406C and S and HDPE PE3408S are unimodal materials. The short-term properties of the two PE2406 resin materials are very close. Bimodal HDPEs have a higher density and display higher flexural modulus and tensile strengths over conventional HDPE.

PRESSURE CAPABILITY

When designing a natural gas pipeline, utility companies expect them to operate safely for 50 years. It is well known that the strength of plastics is dependent on time and temperature. It is not realistic to test the pipe materials for 50 years in the real world. A good scientific method is needed to extrapolate the 50-year performance based on relatively short term testing data. ASTM D2837 and ISO 9080 have been used for many years to pressure-rate the plastic materials based on hydrostatic test data with a minimum testing time of 10,000 and 9,000 hours, respectively. HDB-rated and MRS-rated materials have been successfully used in the field for several decades in North America and the rest of the world (mainly in Europe), respectively.

HDB-Rated Materials

ASTM D2837 first extrapolates LTHS to 100,000 h (11 years) using 18 hydrostatic data points generated at 23°C. It assumes the linearity of the regression curve using the equation of a straight line.

$$\log t = a + b \log S \qquad (1)$$

where a and b are constants, S is the failure stress in psi and t is the failure time in hours. The extrapolation is validated by elevated temperature data using the rate-process method, the three-parameter equation,

$$\log t = A + \frac{B}{T} + \frac{C \log S}{T} \qquad (2)$$

where A, B and C are constants, S is the stress in psi, T is the temperature in °K, and t is the failure time in hours. The LTHS is then categorized into HDB and listed in PPI TR-4.

PE2406 and PE3408 can be used for gas pipe in accordance to ASTM D2513. However, not all PE2406 and PE3408 rated materials are qualified for gas pipe applications. D2513 has additional requirements that include: a minimum 630 psi HDB at 60°C; and HDB at 23°C is substantiated by showing that the extrapolation of the stress regression curve is linear to the 438,000 h intercept (LTHS at 50 years).

Table 3 lists the HDB of six pipe materials at 23°C and 60°C. They meet the pressure rating requirements for natural gas distribution in North America in accordance to ASTM D2513. Note that PE2406S has 1250 psi HDB at 23°C but 1000 psi HDB at 60°C. PE3408S is listed for 1600 psi HDB at 23°C but 800 psi HDB at 60°C. PE2406S offers a higher pressure rating than PE3408S at 60°C.

However, bimodal technology has improved long-term performance in new HDPE resins. It is important to note that PE3408E outperforms PE2406S at all temperature range up to 60°C. Thus, the bimodal PE3408E delivers a better long-term performance than PE2406S at a higher operation pressure and for a broader temperature range, based on HDB listing.

MRS-rated Materials

ISO 9080 extrapolates LTHS to 50 years (438,000 h) based on multi-temperature data. The regression curves can be non-linear using the four-parameter equations.

$$\log t = C_1 + \frac{C_2}{T} + C_3 \log\sigma + \frac{C_4 \log\sigma}{T} \qquad (3)$$

where C_i is a parameter, σ is stress in MPa, T is temperature in °K, and t is failure time in h. The extrapolation and validation is completed by using the same four-parameter equation (3). It requires data at minimum of two temperatures and at least 30 data points at each temperature. All data points are taken into consideration for both extrapolation and validation. The 50-year LTHS at 97.5% of lower confidence limit (LCL) is then categorized into MRS in accordance to ISO 12162 [8]. PPI lists MRS in TR-4.

Table 4 illustrates the ISO 9080 extrapolation results of a black pipe made from PE100E. The four-parameter equation (3) was used for the extrapolation. No ductile-brittle transition knee was detected up to 80°C and 2.5 years for the real data points. The extrapolation time factor, K_e, was used to determine that the ductile-brittle transition would not occur within 250 years at 20°C, 100 years at 40°C and 15 years at 60°C, based on the test data.

Table 3. HDB and MRS of the Pipe Materials Listed in PPI TR-4

Samples	Material Designation	HDB, psi		MRS, MPa		
		23°C[1]	60°C	20°C	40°C	60°C
PE2406C	PE2406	1250*	800			
PE2406S	PE2406	1250*	1000			
PE3408S	PE3408	1600*	800			
PE3408E	PE3408	1600*	1000			
PE100S	PE100	1600*	1000	10.0		
PE100E[2]	PE100	1600*	1000	10.0	8.0	6.3

(1) In PPI TR-4, an asterisk is used to show the compliance of HDB substantiation to 50 years at 23°C.
(2) MRS (Θ, t) is cited from PPI TR-4. Above listings are MRS 10.0 (20°C, 100 years), MRS 8.0 (40°C, 50 years) and MRS 6.3 (60°C, 11 years).

Table 4. ISO 9080 Analysis Results for the Black Pipe Made from PE100E Resin

Number of Data Points*	93
23°C Data	30 points>500 h, 4 points>7000 h and 4 points>9000 h
60°C Data	30 points>10 h, 7 points>7000 h and 3 points>9000 h
80°C Data	33 points>10 h, 11 points>7000 h and 10 points>9000 h
Number of Parameters of the Regression Equation	4
Knee Position	No knee is detected
t_{max} of Average of Longest Five Points at 80°C	21,746 h (2.5 years)
Ductile Extrapolation Limit at 20°C	250 years
Ductile Extrapolation Limit at 40°C	125 years
Ductile Extrapolation Limit at 60°C	15 years
MRS at 20°C for100 years	10.0 MPa
MRS at 23°C for 50 years	10.0 MPa
MRS at 40°C for 50 years	8. 0 MPa
MRS at 60°C for 11 years	6.3 MPa

* Including some non-failure points.

Table 5. Maximum Operation Pressure (MOP) of the Pipe Materials

Samples	Material Designation	MOP, psig			
		20°C	23°C	40°C	60°C
PE2406C	PE 2406		80		51
PE2406S	PE2406		80		64
PE3408S	PE3408		102		51
PE3408E	PE3408		102		64
PE100S	PE 100	145			
PE100E(1)	PE 100	145	145	116	91

(1) MOP is for 20°C/100 years, 23°C/50 years, 40°C/50 years and 60°C/11 years.

To date, ASTM D2513 has not recognized MRS-rated materials. A parallel standard, ISO 4437, may be used provided a DOT waiver is obtained. ISO 4437 requires MRS at 20°C. ISO TC138 has been working on a draft standard that recognizes the MRS (Θ, t), where Θ is the temperature in °C and t is the time in years. MRS (20°C, 50y) must be listed for pipe classification. The end-use engineers shall use MRS (Θ, t) for design consideration. The maximum application temperature should be below or equal to Θ.

To address the important application temperature issue, PPI has listed MRS (Θ, t) in TR-4. As shown in Table 3, PE100E has three new MRS listings in addition to the standard listing of MRS (20°C, 50y). The new listings are MRS 10.0 (20°C, 100 y), MRS 8.0 (40°C, 50 y) and MRS 6.3 (60°C, 11 y).

Maximum Operation Pressure (MOP)

For HDB-rated materials, the MOP is calculated by Equation (4)

$$MOP = \frac{2 \times HDB \times F}{DR - 1} \qquad (4)$$

where HDB is in psi, MOP is in psig, F is a design factor and the dimension ratio DR equals the average outside diameter divided by the minimum wall thickness. For natural gas pipe, F equals 0.32. For a standard SDR 11 pipe, Table 5 calculates MOP of the HDB-rated materials at the temperatures of 23°C and 60°C. Because the HDB at 23°C is substantiated to 50 years, the MOP at 23°C is based on 50-year extrapolation. At the room temperature of 23°C, PE3408 outperforms PE2406. However, at 60°C, the enhanced PE2406S and PE3408E are better than the conventional PE2406C and PE3408S materials.

Let us compare the pressure capability of four HDB-rated materials in the temperature range from 23°C to 60°C. The following equation, as given in PPI TN-18 [9], is used to calculate the pressure rating at a given temperature, T.

$$S_T = S_L - \frac{(S_L - S_H) \times (\frac{1}{T_L} - \frac{1}{T_T})}{(\frac{1}{T_L} - \frac{1}{T_H})} \qquad (5)$$

Where S_T is LTHS at interpolation temperature (psi), S_L is LTHS at the lower temperature (psi), S_H is LTHS at the higher temperature (psi), T_T is the interpolation temperature (°K), T_L is the lower temperature (°K) and T_H is the higher temperature (°K). Using HDB at 23°C and 60°C, the pressure ratings at a temperature between 23°C and 60°C can be calculated by Equation (4). The corresponding MOP is calculated by using Equation (4).

Figure 1 provides the curves of MOP versus temperatures for a standard SDR 11 pipe. Note that: (1) PE2406S and PE3408E offer an MOP

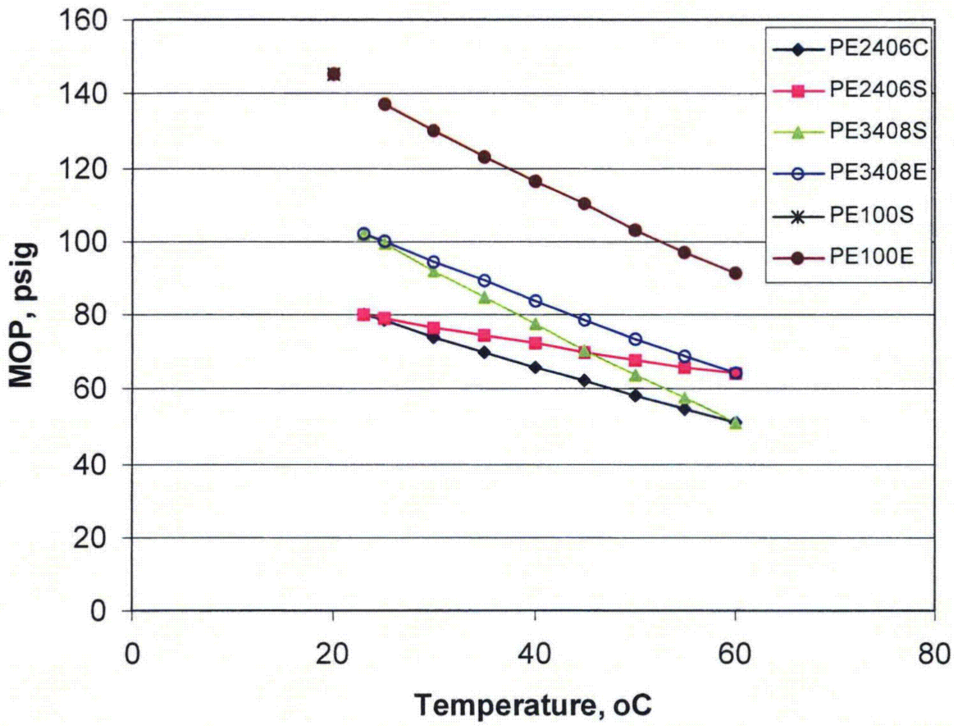

Figure 1. MOP versus Application Temperatures

Table 6. SCG Requirement and PENT hours of the Pipe Materials

Product	Material Designation	SCG Cell Class	PENT, hrs	Typical PENT, hrs
		D3350	D2513	F1473
PE2406C	PE2406	6	>100	2500
PE2406S	PE2406	6	>100	3000
PE3408S	PE3408	6	>100	200
PE3408E	PE3408	6	>100	4000
PE100S	PE 100	6	>100	2000
PE100E	PE 100	6	>100	6000

higher than 60 psig up to 60°C (60 psig operating pressure is widely used in the U.S); (2) PE3408E has a higher MOP than PE2406S for the whole temperature range (at 23°C, the MOP of PE3408E is 28% higher); (3) Below 45°C, PE3408S has higher MOP than PE2406S. However, above 45°C, PE2406S has higher MOP than PE3408S. It is intercepted at 70 psig and 45°C; (4) PE2406C is ranked the last in the group.

From Figure 1, PE3408E offers the best pressure capability at all temperatures. On one hand, for operating pressures above 70 psig and maximum temperatures below 45°C, PE3408S may be better than PE2406S. On the other hand, for operating pressures below 70 psig and maximum temperatures above 45°C, PE2406S might be better than PE3408S. PE2406C is not competitive and should be obsolete. The current market shares of these materials correlate well with the MOP data. PE2406S and PE3408S split the market. PE2406S dominates the market for 70 psig and below. PE3408S is preferred for above 70 psig. PE2406C almost has no sales. It is worth noting that PE3408E should outperform both PE2406S and PE3408S.

For MRS-rated materials, the MOP is calculated by Equation (6)

$$MOP = \frac{20 \times MRS}{C \times (DR - 1)} \qquad (6)$$

where MRS is in MPa, MOP is in bar, C is a design coefficient and the dimension ratio DR equals the average outside diameter divided by the minimum wall thickness. For gas pipe, C equals 2. For a standard SDR 11 pipe, Table 5 listed the calculated MOP value of the MRS-rated materials at the temperatures of 20°C for 50 years. For PE100E, the MOP is 145 psig for 20°C/100years, 145psig for 23°C/50years, 116 psig for 40°C/50years and 91 psig for 60°C/11years. As illustrated in Figure 1, at room temperatures, PE100 has 42% and 81% pressure advantage over PE3408 S and E and PE2406 C and E, respectively. In addition, at 60°C, PE100E also offers 42% pressure advantage over both PE2406S and PE3408E, and 78% advantage over both PE2406C and PE3408S.

In the United States, the Department of Transportation (DOT) regulates the transportation and distribution of natural gases. The DOT has approved an American Gas Association (AGA) petition to increase the maximum allowable operation pressure (MAOP) of PE pipe from 100 to 125 psig. However, to date, this MAOP increase has not been published. Besides, the DOT and ASTM D2513 do not recognize MRS-rated materials. Currently, only HDB can be used to calculate MOP in the U.S. A waiver is required from the DOT if using MRS-rated materials.

WHAT CAUSES A PIPING SYSTEM TO FAIL

A gas pipe may fail in the following three modes.

1. Ductile, the Stage I failure with large-scale deformation;
2. Slow crack growth, the Stage II brittle failure with a very small leaking hole; and
3. Rapid crack propagation, the fast failure mode with the crack running at a speed up to hundreds of meters per second.

Pipe systems rarely fail in the ductile mode since the hoop stress of a pressurized gas pipe is far below the yield point after considering the safety factor. For example, the hoop stress of a PE3408 pipe is about 14% to 32% of the yield strength within 50 years.

A pipe resin's resistance to SCG is the most important factor in determining the lifetime of a gas pipe system. All long time failures are caused by SCG. When the failure rate becomes excessive in any part of the system, it must be replaced. The six factors that determine failure rates are:

1. Quality of the resin;
2. Quality of the fusion joints;
3. Operation pressures;
4. Temperatures;
5. Installation/earth movement; and
6. Third party damages.

RCP failure is also extremely rare but catastrophic. Five factors related to RCP include:

1. Resin quality;
2. Operating pressures;
3. Temperatures;
4. Pipe diameters; and
5. Third party impact.

Regardless of the quality of the initial installation, many uncontrollable events can occur when the ground around the pipe settles naturally or is disturbed by third party excavations. The third party impact is the most common initiator of RCP failures.

Many long-term failures occur at the fusion joints. The fusion joints are a source of stress concentration that, together with the stress, determines the rate of SCG. Its quality primarily depends on the ability of the welder to consistently produce a good weld. The resistance to SCG of the material itself plays an important role to determine the failure rate.

The quality of the resin is the most important factor in determining the lifetime of a gas pipe system. The resin property that determines the lifetime is its resistance to SCG. Whatever abuse a gas pipe system experiences as a result of excessive ground stresses, scratches during installation, or poorly fusion joints, gas pipe infrastructure consisting of a resin with a high resistance to SCG will have a longer lifetime than one with a lower resistance.

Brown and Lu [12] collected the failure data from six gas utility companies. The PENT lifetimes of the resins were measured and they were from less than 1 hour up to 50 hours. The service lifetimes ranged from 8 to 25 years. If the failure rate is defined as the number of failures per mile pipeline per year, the field failure rate can be correlated to the PENT hours. It was found that as the PENT hours increased, the failure rate dramatically decreased.

RESISTANCE TO SLOW CRACK GROWTH (RSCG)

The key to obtaining a long service lifetime is to install pipes and fittings made of a resin with a better RSCG. Higher RSCG resin has the following advantages.

1. Better resistance to stresses;
2. Better resistance to temperatures;
3. Better resistance to scratches and other third party damages; and
4. Stronger fusion joints due to higher tolerances of defects.

For the same operation conditions, a pipe system with better RSCG will last longer by slowing crack growth or penetration. Also, the impact of scratches or third party damages is less severe due to the greater resistance to crack growth. A poorly fusion joint may cause premature failures but fusion joints using better RSCG resin may still have a very long residual lifetime. For example, a joint with a defect of 10% of the wall thickness, which is introduced either from fusion joining or from other damages, can fail earlier in SCG mode. If everything is the same the joint from a resin with 4000 h PENT is expected to last 40 times longer than that from a resin with 100 h PENT.

The PENT test has been used worldwide as an accelerated method to mimic SCG in the field. A SCG is initiated at the tip of a defect or crack. Defects or cracks can be introduced into the pipe wall:

1. During the pipe extrusion process;
2. When joining parts of the pipe together;
3. By scratching the pipe surfaces during installation;
4. During ground movement or third party excavations;
5. By rock impingement from the "hard" objects in the soil beds; and
6. Through an uncontrollable event in the field;

It is difficult to estimate the size and sharpness of the defects or cracks in the pipe wall and its consequential effect on the service lifetime. The PENT test measures the resistance to SCG by introducing the worst defects.

Assume no defects or cracks are sharper than the tip of a razor blade and larger than 35% of the pipe wall in size. PENT test uses a specimen with a 35% initial notch made by a fresh razor blade. This represents the worst case that can happen in a pipe wall. The RSCG as measured by PENT is related to the pure resistance of the resin material to SCG.

ASTM D2513 requires a minimum of 100 h PENT for gas pipe. The PENT test is conducted at 80°C and 2.4 MPa on compression-molded and slow-cooled specimens with 35% of notch depth. Table 6 lists the minimum SCG requirement and the typical values of the pipe materials investigated.

MD PE2406S has the PENT hours at 15 times higher than that of unimodal PE3408S. This is another reason why PE2406S is preferred for natural gas distribution in addition to a higher HDB at 60°C than PE3408S.

The new bimodal PE3408E has PENT hours at 20 times higher than PE3408S. It is also better than PE2406S. In fact, the PENT of PE3408E is at least 30% higher than that of PE2406S, indicating increased RSCG.

One design goal of bimodal HDPE pipe resin is to achieve a combination of the strength offered by HDPE and the toughness offered by MDPE. As a matter of fact, it has been seen that the bimodal materials have higher-pressure ratings than unimodal HDPE. Table 6 shows that the three bimodal HDPE resins (PE3408E, PE100S, and PE100E) have similar or better RSCG compared to MDPE. In particular, PE100E doubles the PENT of PE2406S.

RAPID CRACK PROPAGATION (RCP)

RCP failures have been observed in the field for both steel and PE pipes. A crack may be initiated by a third party impact for a gas-pressurized pipe. The crack can propagate at a speed up to 300 meters per second, under the driving force of the internal gas pressure. This phenomenon is called RCP failure.

We have discussed the factors that determine RCP failures in the previous part of this paper. There is little doubt that the resin materials make a big difference in preventing RCP failures. As pipe diameters (for a given SDR) and/or internal pressures increase, more energy is stored in the pipe. The driving force for crack propagation becomes greater. It is more likely to have a RCP failure. When the ambient temperature is lower, the pipe materials are more brittle. Here, most RCP failures are initiated by a third party impact.

ISO 13477 (S-4 test) [13] and ISO 13478 (Full Scale) are used to measure the RCP property. These standard methods measure the transitions the crack runs to the end of the pipe specimen and where the crack is stopped shortly after it is initiated. For a given pipe specimen, the critical internal pressure can be measured when fixing the temperature at 0°C. This critical internal pressure is called critical pressure, Pc. When the internal pressure is a constant, usually 10 bar, the transition temperature can be measured. This transition temperature is called critical temperature, Tc.

ISO 4437 requires a minimum Pc for gas pipe.

$$Pc(S-4) \geq \frac{MOP}{2.4} \quad (7)$$

$$MOP(RCP) = 2.4 \times Pc(S-4) \quad (8)$$

For PE100, the minimum Pc is 4.2 bar. Taking into consideration of both long-term pressure rating of MRS and RCP, the final MOP will be the smaller of the values calculated from Equation (6) and (8).

It is important to point out the effect of pipe diameters when measuring RCP property. For a given SDR, the S-4 Pc decreases as the pipe diameter increases. To date, ISO 4437 requires a minimum of 160 mm diameter (6 inches) SDR 11 pipe for S-4 test. The European standard requires 250 mm diameter (10 inches) SDR 11 pipe. Since S-4 Pc increases as decreasing pipe diameters, a pipe material with less RCP resistance can be restricted to the applications of low operating pressures and/or for small diameter pipes.

The S-4 Pc is measured at 0°C. It does not give information regarding the RCP resistance at below 0°C. The gas pipe industry, especially in Europe, begins using S-4 Tc to evaluate the RCP resistance, realizing that the ambient temperatures might be below zero. ISO 4437 requires 4.2 bar S-4 Pc for PE100. When measuring S-4 Tc, the internal pressure is fixed to 10 bar, about 2.4 times higher than the PE100 requirement. It means that at S-4 Tc, the RCP Pc is 10 bar. This will assure that RCP failures will not occur if the application temperatures are above Tc.

A Gas Research Institute (GRI) report [11] measured the S-4 Tc of ten PE gas pipe. The

Table 7. S-4 RCP Property of the Pipe Materials

Samples	Material Designation	Tc, °C	Pc, bar	Pc, bar
		ISO 13477	ISO 4437	ISO 13477
PE2406C	PE2406	18 – 33 [11]		
PE2406S	PE2406	18 – 33 [11]		
PE3408S	PE3408	9 –19 [11]		
PE3408E	PE3408	< -17		>12
PE100S	PE100		4.2	>10
PE100E	PE100	< -17	4.2	>12

Table 8. Butt Fusion Jointed Pipe Specimens and the Hydrostatic Test Matrix

Hydrostatic Test	Failure Times of Butt Fusion Jointed Samples, hours							
	PE3408E	PE100E	PE3408S	PE2406C	PE3408E	PE100E	PE100E	PE3408E
	PE3408E	PE100E	PE3408S	PE2406C	PE3408S	PE3408S	PE2406C	PE2406C
23°C, Burst	X	X	X	X	X	X	X	X
23°C, 1800 psi	254	254	67	X	61	61	X	X
23°C, 1600 psi	X	X	X	X	X	X	X	X
23°C, 1320 psi	X	X	X	X	X	X	X	X
80°C, 800 psi	X	X	X	X	X	X	X	X
80°C, 725 psi	X	X	X	X	X	X	X	X
80°C, 580 psi			X	X				
80°C, 841 psi		X						
90°C, 700 psi		X						
90°C, 483 psi			X	X				

Table 9. Quick Burst of Butt Fusion Jointed 22" SDR 9 PE100E pipe

Pipe Sample	PE100E
Pipe Outside Diameter, inches	22.025
Minimum Wall Thickness, inches	2.496
Test Condition	23°C
Internal Pressure, psig	1090
Hoop Stress, psi	4264

resins and pipes were manufactured in North America. The test specimens were a piece of 8" SDR 11 pipe with a length of greater than 56". The S-4 Tc of five MDPE and five HDPE unimodal pipes are listed in Table 7, respectively. The S-4 Tc of the 10 unimodal PE gas pipes was above 9°C. PE3408S had relatively better RCP resistance than PE2406S and PE2406C.

The S-4 Tc of PE3408E and PE100E was measured on 10" SDR 11 pipe. Becetel in Belgium conducted the S-4 test. The results are listed in Table 7. They are much better than the unimodal gas pipe materials. For PE3408E and PE100E, the RCP failures will not happen if the application temperatures are above −17°C, at an internal pressure of 24 bar (360 psig) for a SDR 11 pipe. On contrary, at an application below 9°C, the best unimodal gas pipe in today's market may fail in RCP.

ASTM D2513 does not require RCP property. AGA PMC has sent a letter to ASTM F17 to request a RCP requirement in D2513. An AGA white paper to gas utilities suggests utility companies take ISO 4437 as a reference for RCP property before a RCP requirement is incorporated in D2513.

BUTT-FUSION JOINTS

Fusion joints represent the weakest point in a pipeline system. Because the field failures typically occur within the pipe joints, the quality of butt-fusion joints is important.

The compatibility of a pipe made of the new bimodal resins with an existing pipeline, made from unimodal PE, is important for the integrity of the infrastructure. It is necessary to generate data for the cross fusion joints between the new bimodal HDPEs and the existing unimodal gas pipe materials.

An extensive program has been initiated by Dow to investigate the quality of butt-fusion joints. 1" SDR 11 pipe was made in a Dow pilot plant. The pipe samples were shipped to McElroy. They were butt-fusion jointed together by McElroy using the PPI generic fusion joining procedure TR-33 [10]. The fusion jointed pipe samples were sent back to Dow Pipe Technology Center for evaluation and testing.

Four pipe materials were used for this research: two existing unimodal materials of PE2406C and PE3408S; two new bimodal materials of PE3408E and PE100E. It resulted in eight butt-fusion jointed samples: four homogeneous welds made from the same pipe of these four materials, respectively; two cross fusion joints of PE3408E with PE2406C and PE3408S, respectively; and two cross fusion joints of PE100E with PE2406C and PE3408S, respectively. Table 8 lists these eight butt-fusion jointed samples.

The objectives of the hydrostatic test on the butt-fused pipe specimens are:

1. To prove that the pipe with joints exceeds the requirements of ASTM D2513 or/and ISO 4437;

2. To provide information to support the hypothesis that the cross fusion joint of a better material and a conventional material would be better than the conventional pipe itself and the joint between the conventional pipe; and

3. To experimentally show that a PE100E pipe will outperform a PE3408 pipe in a long run even if it is subject an internal pressure of 45% higher than PE3408S.

At least three specimens were tested for each test condition. The partial results were listed in Table 8. This program is still on going.

Figure 2 showed the butt-fusion jointed 1" SDR 11 pipe samples. Sample a and b were butt-fusion jointed from same pipe of PE100E and PE3408E, respectively. Samples c and e were for the cross fusion of PE3408E with PE2606C and PE3408S, respectively. Samples f and g were for the cross fusion of PE100E with PE2406C and PE3408, respectively. By visually examining the beads, all welds were in good quality.

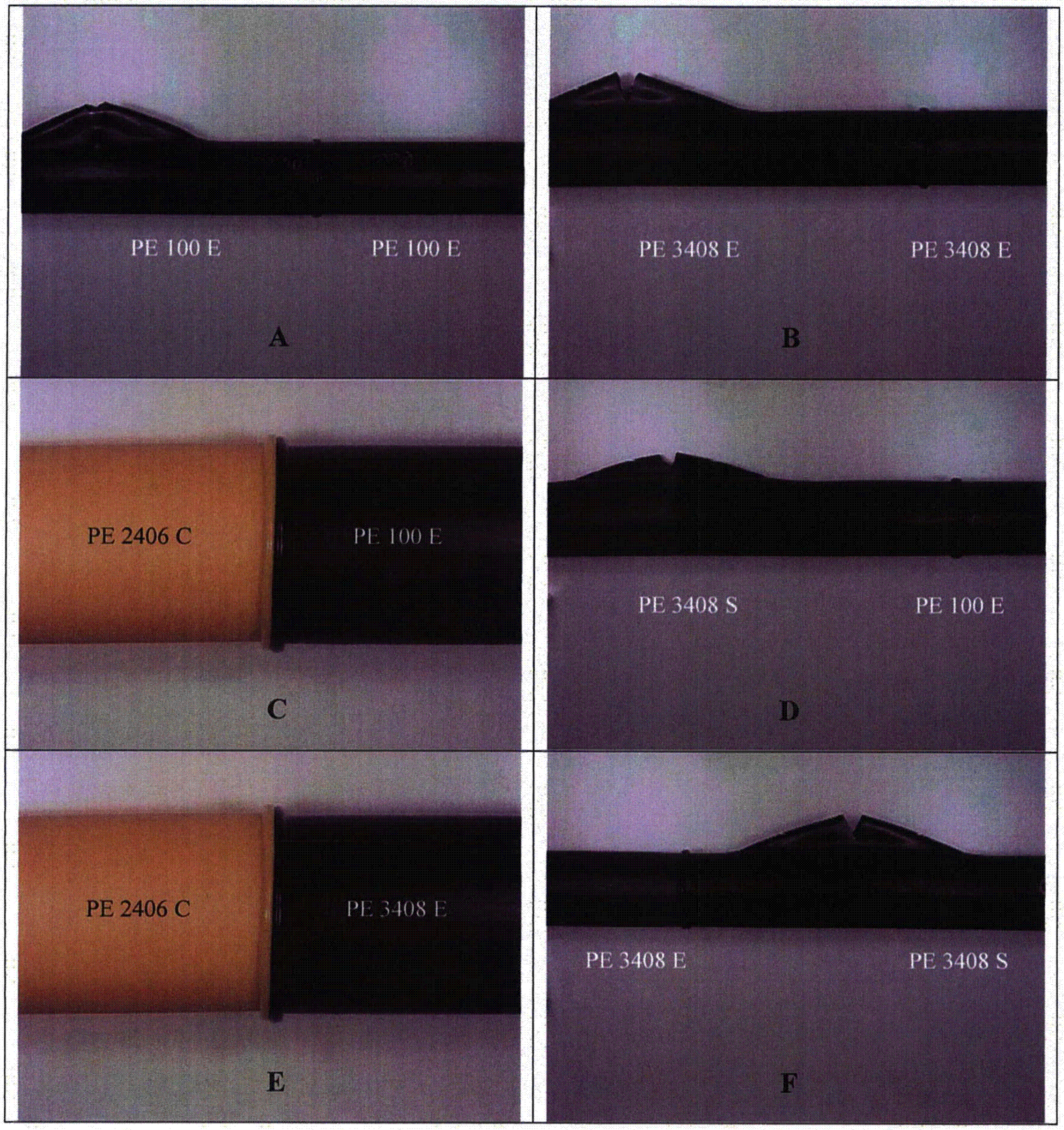

Figure 2. Butt Fusion Jointed 1" SDR 11 Pipe

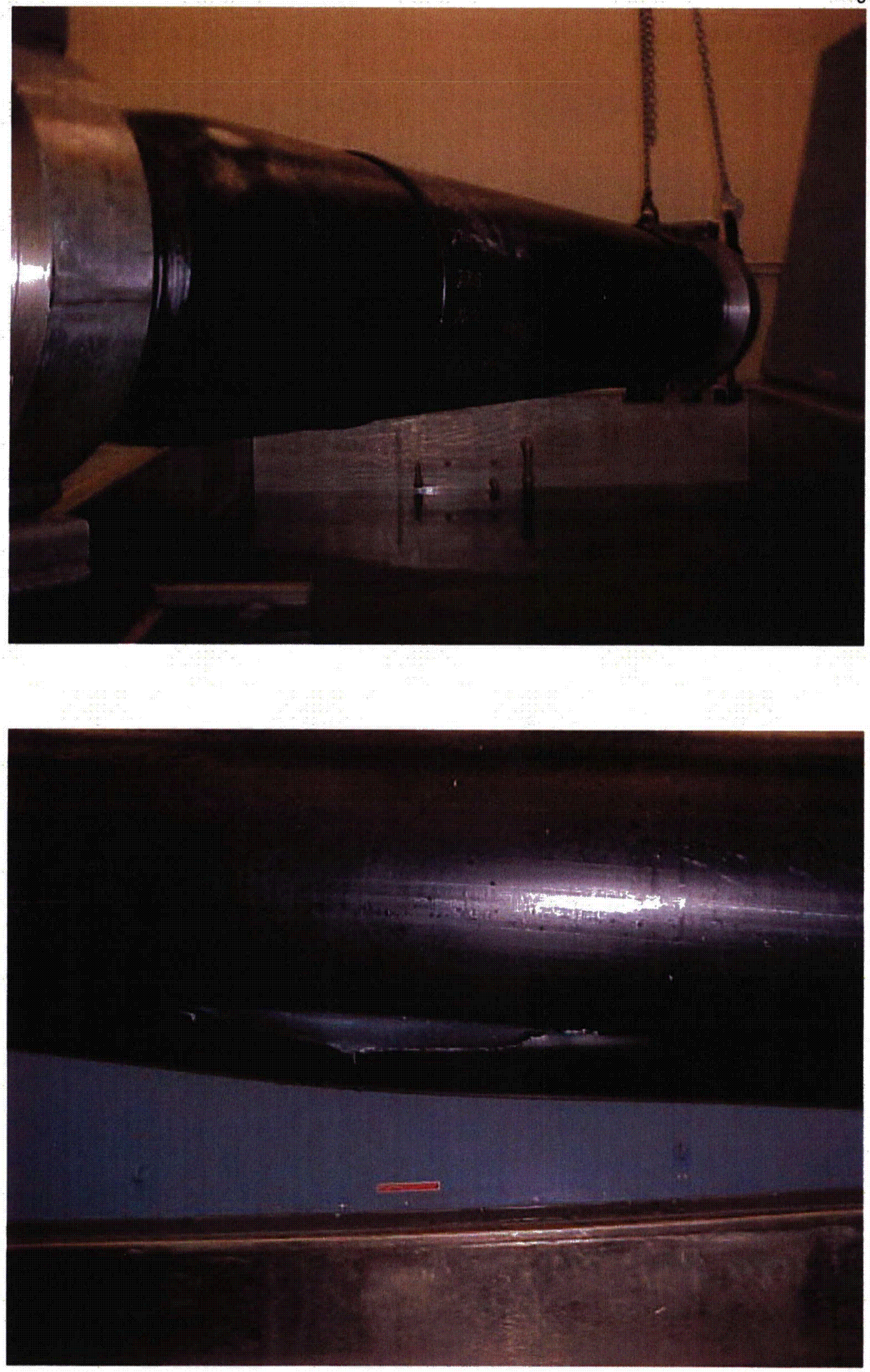

Figure 3, Quick Burst Test of 22" SDR 9 Pipe Made from PE100E.

Table 10. The McSnapper ™ Test Data by McElroy for 8" SDR 11 Pipe

Samples	Interfacial Pressure, psi		Yield Energy (ft-lbs)	Failure Energy (ft-lbs)	Maximum Force (lbs)	Ultimate Stress (psi)
PE100E-PE100E	60	avg	19	83	1234	4031
		std dev	1.5	12	21	79
	90	avg	18	77	1226	4010
		std dev	1.6	3	25	64
PE100E-PE3408S	60	avg	17	67	1172	3908
		std dev	1.0	4	14	39
	90	avg	17	61	1142	3775
		std dev	1.0	11	31	93
PE100E-PE2406S	60	avg	14	57	1056	3418
		std dev	0.6	5	25	67
	90	avg	13	57	1055	3459
		std dev	0.5	1	15	43
PE3408S-PE3408S	60	avg	19	75	1128	3636
		std dev	2.1	9	18	63
	90	avg	19	68	1135	3695
		std dev	1.9	8	15	35
PE100E	No joint	avg	18	87	1201	3964
		std dev	0.8	5	16	60
PE3408S	No joint	avg	19	85	1118	3701
		std dev	1.0	5	40	110

Figure 2 also showed the locations where the failures occurred. First, there was no failure that took place at the joints, indicating an excellent quality of the welds that include the cross fusion samples. Second, the failures were always on the PE3408S side for the cross fusion samples, indicating that both PE100E and PE3408E performed better. At the condition of 23°C and 1800 psi, both PE3408E and PE100E performed about 4 times better than PE3408S, see Table 8.

Larger diameter pipe was also tested for fusion joining and burst pressure. A pipe manufacturer extruded a 22" SDR 9 pipe from PE100E. The pipe was butt-fusion jointed using PPI generic fusion joining procedure of TR-33 by the same pipe manufacturer. The quick burst test was conducted at 23°C. The test result was listed in Table 9. The failed specimen was shown in Figure 3.

The fusion joining of large diameter PE100E pipe was no significant difference from PE3408S. It produced a very uniform bead. The butt-fusion jointed pipe failed at outside the joint, indicating the joint was stronger than the bulk pipe for short-term. The hoop stress was 4264 psi, 69% higher than the requirement of 2520 psi.

McElroy developed the McSnapper ™ machine specifically for polyolefinic materials to accurately test fusion joints. The McSnapper ™ combines the tensile impact test ASTM D1822 and high-speed tensile test of ASTM 2289 to provide an accurate test for fused joints. PE100E, PE3408S and PE2406S were chosen for the study. The extruded 8" SDR11 pipe was butt-fused by McElroy using PPI TR-33 procedure [10]. Two interfacial pressure (60 psi and 90 psi) were used. They are the minimum and maximum interfacial pressure in PPI TR-33. Four specimens from each joint configuration were fabricated using a McElroy Coupon Cutter. In addition to these samples, coupons were cut from pipe wall of PE100E and PE3408S to serve as controls for this study. Table 10 lists the samples and the test results for the McSnapper ™ test.

All the failures occurred in the pipe sidewall and none occurred at the actual fusion joints. Additionally, no brittle failures were observed. The data showed that joints of like pipes made from PE100E displayed excellent strength compared to control samples without fusion joints. The cross fusion of PE100E with PE3408S was stronger than joints of PE3408S with PE3408S, and even stronger than the PE3408S pipe itself. It appeared that PE100E could be butt-fused for good quality joints not only with itself but also with PE3408S and PE2406S.

SUMMARY

1. Among the PE gas pipe materials currently used in North America, MDPE PE2406S is the preferred choice for small diameter pipe and low operation pressures below 70 psig. Two key properties are attributed to the outstanding long-term performance. One is the 1000 psi HDB at 60°C. The other one is the resistance to SCG that is about 10 times higher than that of unimodal PE3408S material. For operation pressures above 70 psig, PE3408S is widely used. PE2406C is less competitive.

2. Bimodal PE3408E HDPE material outperforms all unimodal PE pipe materials including both MDPE PE2406S and HDPE PE3408S. It has a higher-pressure capability than PE2406S at 23°C and higher-pressure capability at 60°C than PE3408S. Its resistance to SCG is better than MDPE PE2406S and PE3408S. Its resistance to RCP has a step improvement over PE2406S and PE3408S. It can be butt-fusion jointed with itself or PE2406C or PE3408S with high quality. Preliminary data indicated that the butt-fusion joints between this bimodal HDPE and other PE3408 were stronger than the pipe itself made from PE3408S. Based on these data, the bimodal PE3408E will perform better than both PE2406S and PE3408S. It can be used for new pipeline installations and replacement or improvement of an existing pipeline.

3. PE100 bimodal resin opens opportunities for natural gas piping with improved pressure capability and resistance to SCG and RCP. It offers 42% higher-pressure capability over PE3408 around room temperatures. The PENT lifetime is at least 10 times longer than the minimum requirement of 100 h.

4. Enhanced PE100E has additional advantages over other PE100. It has 100-year MRS 10.0 listing at 20°C, 50-year MRS 8.0 at 40°C and 11-year MRS 6.3 at 60°C. It can be used for application temperatures up to 60°C. It offers higher-pressure capability over PE3408 and PE2406 at the temperature range from the room temperature up to 60°C.

5. There is no barrier to use the bimodal PE3408E in the United States. PE 100 can be used outside of North America.

6. MRS-rated materials have been listed in PPI TR-4. ASTM D3350 has recognized MRS-rated PE materials. However, D2513 does not recognize MRS–rated materials. DOT regulations require HDB for calculating the MOP. A DOT waiver may be required for using PE100 materials in the United States. AGA is preparing a petition to DOT for recognizing MRS-rated materials in CFR title 49 part 192.

ACKNOWLEDGMENTS

McElroy butt-fused all 1" SDR 11 and 8" SDR 11 pipe. They also tested the 8" SDR 11 joints using the McSnapper ™ machine. Alan Jedic and Norman Chin of the Dow Pipe Technology Center conducted the PENT and hydrostatic test.

REFERENCES

1. ASTM D2837-01 "Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials"

2. ISO/FDIS 9080-02 "Plastic Piping and Ducting Systems – Determination of Long-term Hydrostatic Strength of Thermoplastics Materials in Pipe Form by Extrapolation"

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

4. ASTM F1473-01 "Standard Test Method for Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipes and Resins"

5. ASTM D2513-01 "Standard Specification for Thermoplastic Gas Pressure Pipe, Tubing, and Fittings"

6. ISO 4437-97 "Buried Polyethylene (PE) Pipes for the Supply of Gaseous Fuels – Metric Series – Specifications"

7. ASTM D3350-02 "Standard Specification for Polyethylene Plastics Pipe and Fittings Materials"

8. ISO 12162-95 "Thermoplastic Materials for Pipes and Fittings for Pressure Applications – Classification and Designation – Overall Service (Design) Coefficient"

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10. PPI TR-33/2001 "Generic Butt Fusion Joining Procedure for Polyethylene Gas Pipe"

11. GRI Report "Impact Test that Predicts the Critical Temperature (CT) for Rapid Crack Propagation (RCP) in PE Gas Pipes', Contract #5092-260-2356, 1998

12. N. Brown and X. Lu, "Controlling the Quality of PE Gas Piping Systems by Controlling the Quality of the Resin", 13th International Plastic Fuel Gas Pipe Symposium, San Antonio, TX, 1993, p327

13. ISO 13477 "Thermoplastics Pipes for the Conveyance of fluids – Determination of resistance to rapid crack propagation (RCP) – Small-Scale Steady-State (S-4 Test) "

New Products, New Horizons: High Density Polyethylene (HDPE) Resins for Natural Gas Piping

Z. Jimmy Zhou, David W. Kababik, Guylaine St. Jean and Quentin D. Eberhart
Pipe Technology Center, The Dow Chemical Company

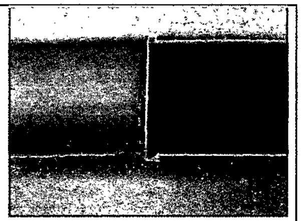
17th International Plastic Fuel Gas Pipe Symposium
October 22, 2002, San Francisco

Outline

- Introduction
- Key Properties
  - Pressure capability (HDB/MRS)
  - Slow crack growth (SCG)
  - Rapid crack propagation (RCP)
- Fusion joints
- Summary

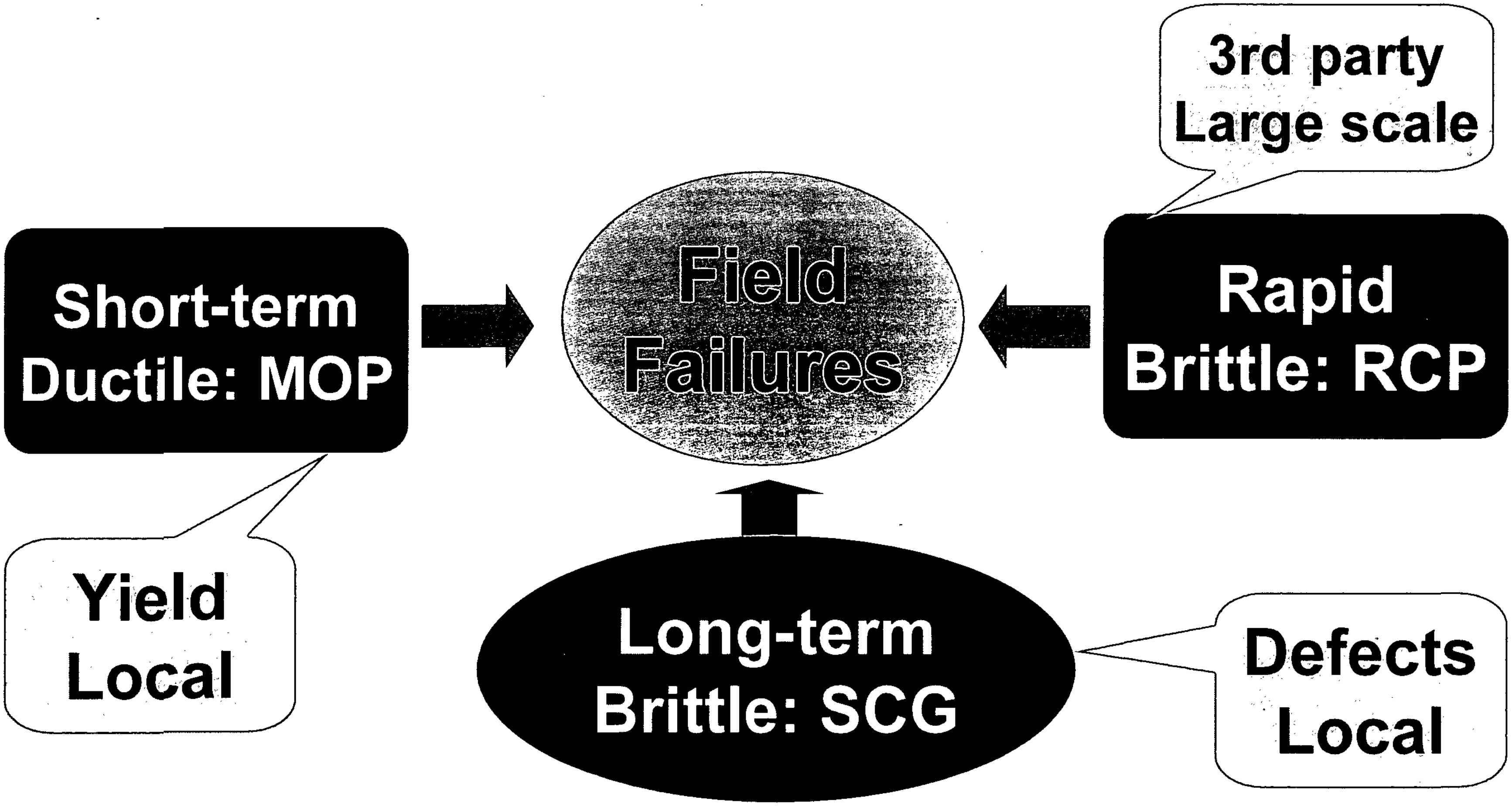
What if Your Pipeline was Human?

- Gas Pipe
  - Leak
  - Time to failure
  - HDB/MRS
  - SCG
  - RCP
  - Fusion joints

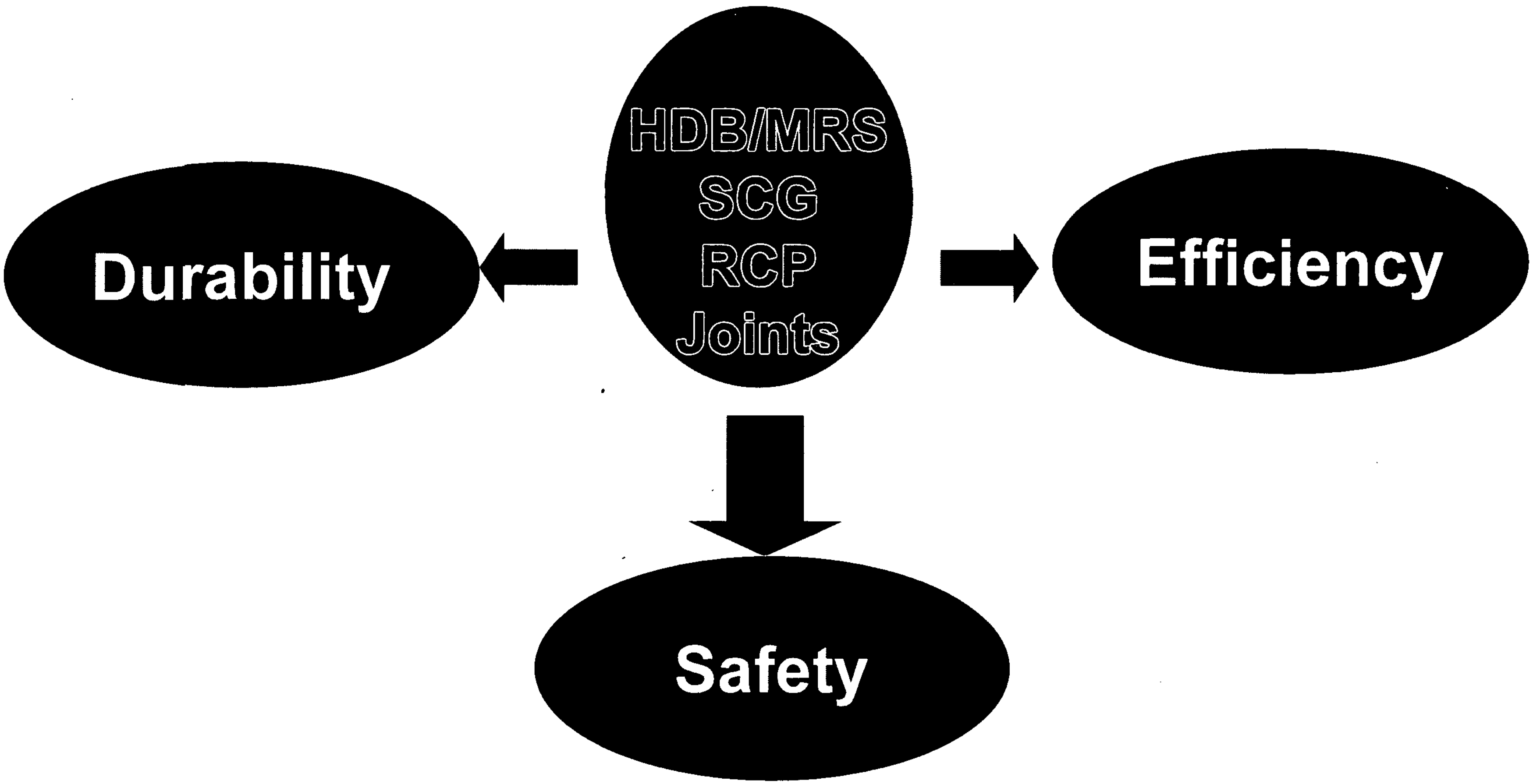


- Human Being
  - Death
  - Lifetime
  - Time dependent strength
  - Health
  - Sudden death
  - Joints

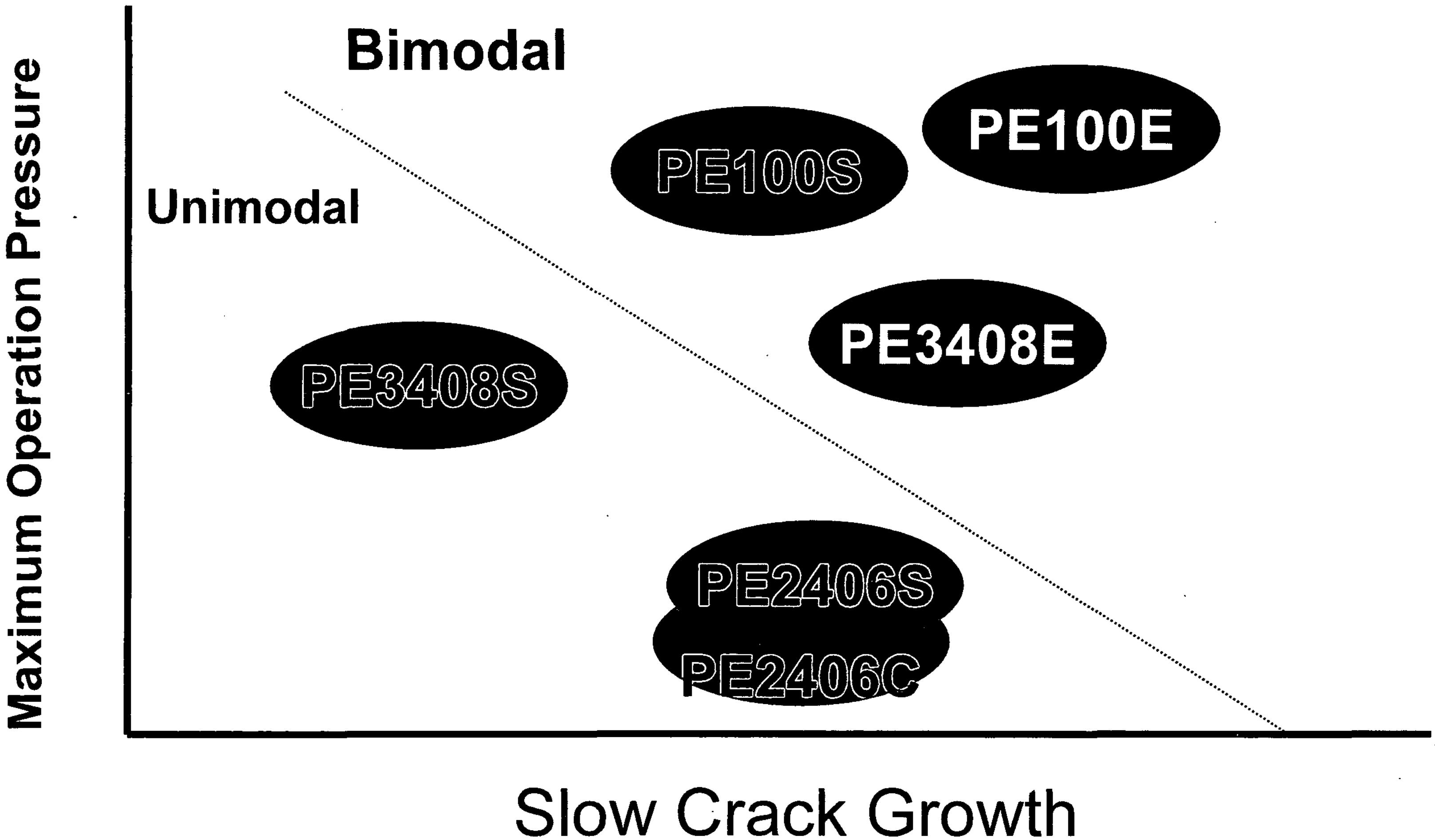
How Pipelines Can Fail in Service



Pipeline Design/Operation Considerations



PE Pipe Materials In North America



DOW

Material Designation

Samples	Material Designation			
	ASTM D3350, PPI TR-4	ASTM D2513	ISO 9080 ISO12162	ASTM D3350
	Pipe Grade	Pipe Category	Pipe Grade	Cell Classification
PE2406C	PE2406	CDC		234363A
PE2406S	PE2406	CEC		234363A
PE3408S	PE3408	CDC		345464C
PE3408E	**PE3408**	**CEC**		**346564C**
PE100S			PE100	345566C
PE100E			**PE100**	**346566C**

CEC rating for PE3408 E

Stronger and Tougher

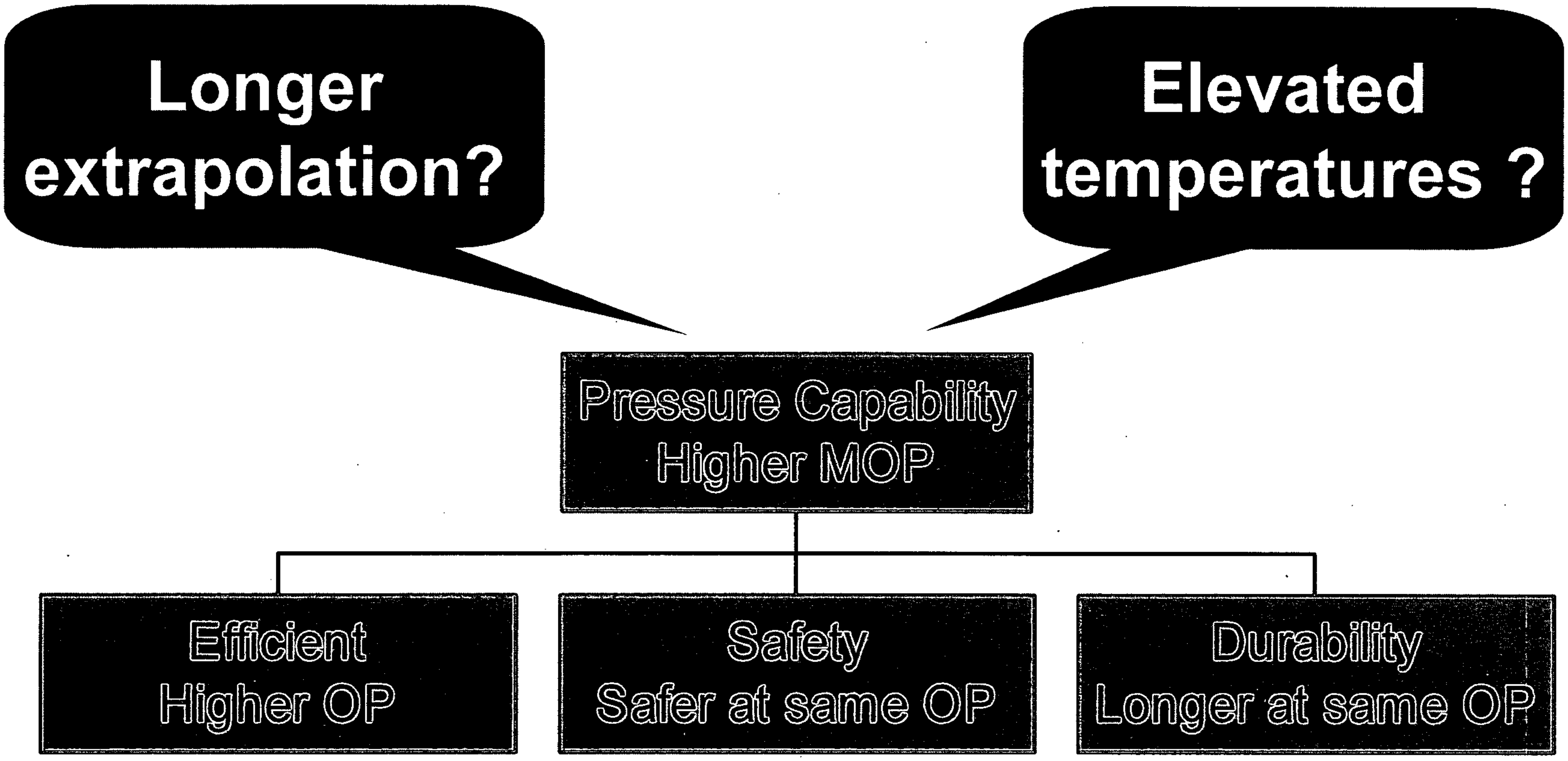
DOW

Material Characterization

Property	PE2406		PE3408		PE100	
	C	S	S	**E**	S	**E**
Technology	Gas Phase	Slurry	Gas Phase	**Gas Phase**	Slurry	**Gas Phase**
Molecular Structure	Unimodal	Unimodal	Unimodal	**Bimodal**	Bimodal	**Bimodal**
Melt Index, I_2	0.2	0.2	0.1	**0.08**	0.1	**0.08**
Flow Index, I_{21}	18	20	8.3	**9**	6.8	**9**
Resin Density	0.939	0.940	0.944	**0.949**	0.951	**0.949**
Flexural Modulus, psi	100,000	100,000	126,000	**165,000**	140,000	**165,000**
Tensile Strength at Yield, psi	2,800	2,800	3,200	**3,600**	3,700	**3,600**

Dow offers
PE3408 E
(DOW DGDC-2480 HDPE Resin);
and
PE100 E
(DOW DGDA-2490 HDPE Resin

Pressure Capability



DOW

Longer Extrapolation by ISO9080

Extrapolation Method	ISO 9080
23°C Data	30 points>500 h, 4 points>7000 h and 4 points>9000 h
60°C Data	30 points>10 h, 7 points>7000 h and 3 points>9000 h
80°C Data	33 points>10 h, 11 points>7000 h and 10 points>9000 h
Number of Parameters of the Regression Equation	4
Knee Position	No knee is detected
t_{max} of Average of Longest Five Points at 80°C	21,746 h (2.5 years)
Ductile Extrapolation Limit at 20°C	250 years
Ductile Extrapolation Limit at 40°C	125 years
Ductile Extrapolation Limit at 60°C	15 years
MRS at 20°C for100 years	10.0 MPa
MRS at 23°C for 50 years	10.0 MPa
MRS at 40°C for 50 years	8. 0 MPa
MRS at 60°C for 11 years	6.3 MPa

PE100 E: 250 year extrapolation is validated

$$t_e = K_e t_{max}$$

DOW

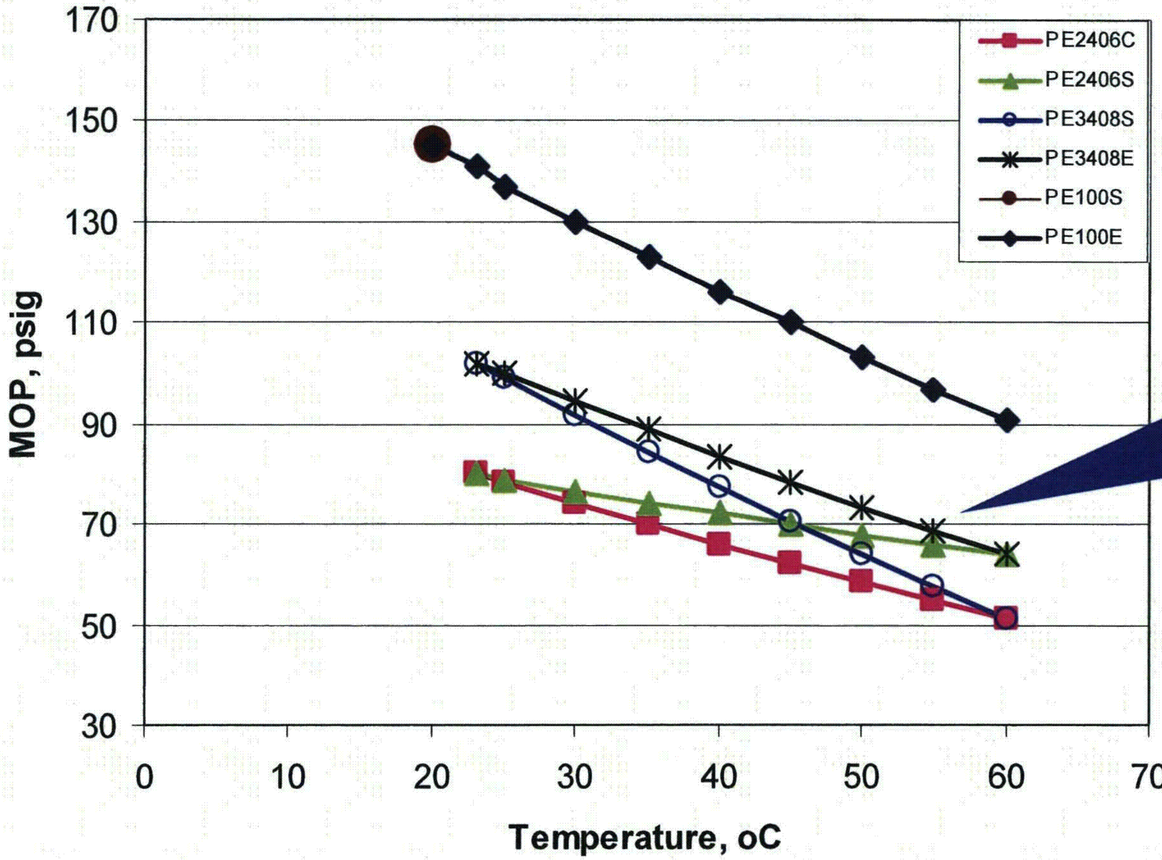
HDB/MRS Listing in PPI TR-4

Samples	Material Designation	HDB, psi		MRS, MPa		
		23°C	60°C	20°C	40°C	60°C
PE2406C	PE2406	1250*	800			
PE2406S	PE2406	1250*	1000			
PE3408S	PE3408	1600*	800			
PE3408E	**PE3408**	**1600***	**1000**			
PE100S	PE100		1000	10.0		
PE100E	**PE100**		**1000**	**10.0**	**8.0**	**6.3**

* Substantiation of 50-y LTHS

20°C for 100-y, 40°C for 50-y and 60°C for 11-y; Also a PE100 at 23°C

Maximum Operation Pressure, SDR 11 Pipe



PE3408 E outperforms other HDB-rated materials

Slow Crack Growth (SCG)

SCG resistance controls field failure rates

PENT Hours The Longer, The Better

SCG
PENT hours

Major failure mode in field

PENT
Correlates with field failure rates

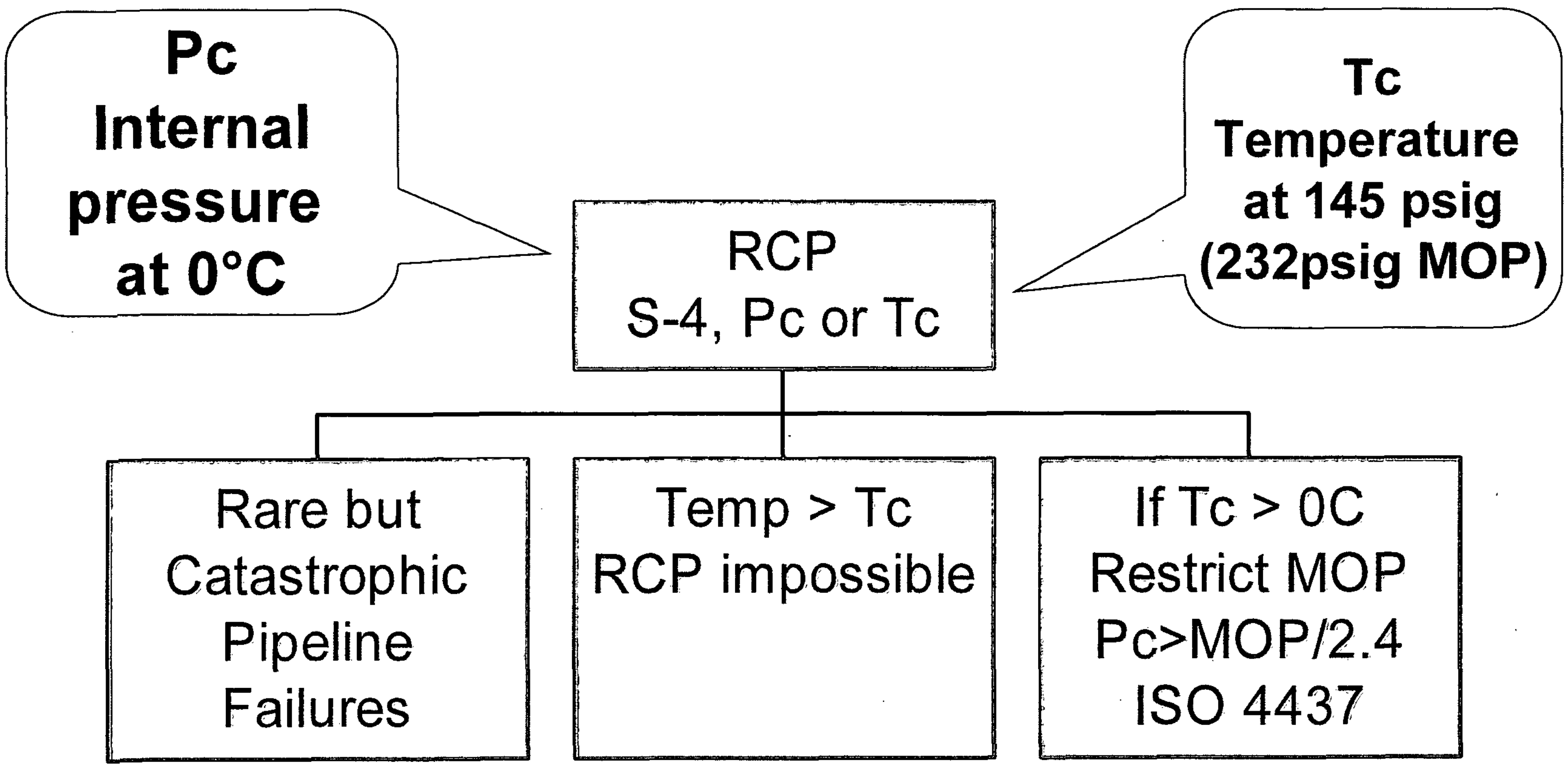
>100 h PENT
ASTM D2513
Requirement

Slow Crack Growth (SCG)

Product	Material Designation	SCG Cell Class D3350	PENT, hrs D2513	Typical PENT, hrs F1473
PE2406C	PE2406	6	>100	2500
PE2406S	PE2406	6	>100	3000
PE3408S	PE3408	6	>100	200
PE3408E	**PE3408**	**6**	**>100**	**4000**
PE100S	PE 100	6	>100	2000
PE100E	**PE 100**	**6**	**>100**	**6000**

PE3408 E is better than PE2406 C and S; and much better than PE3408 S

Rapid Crack Propagation (RCP)



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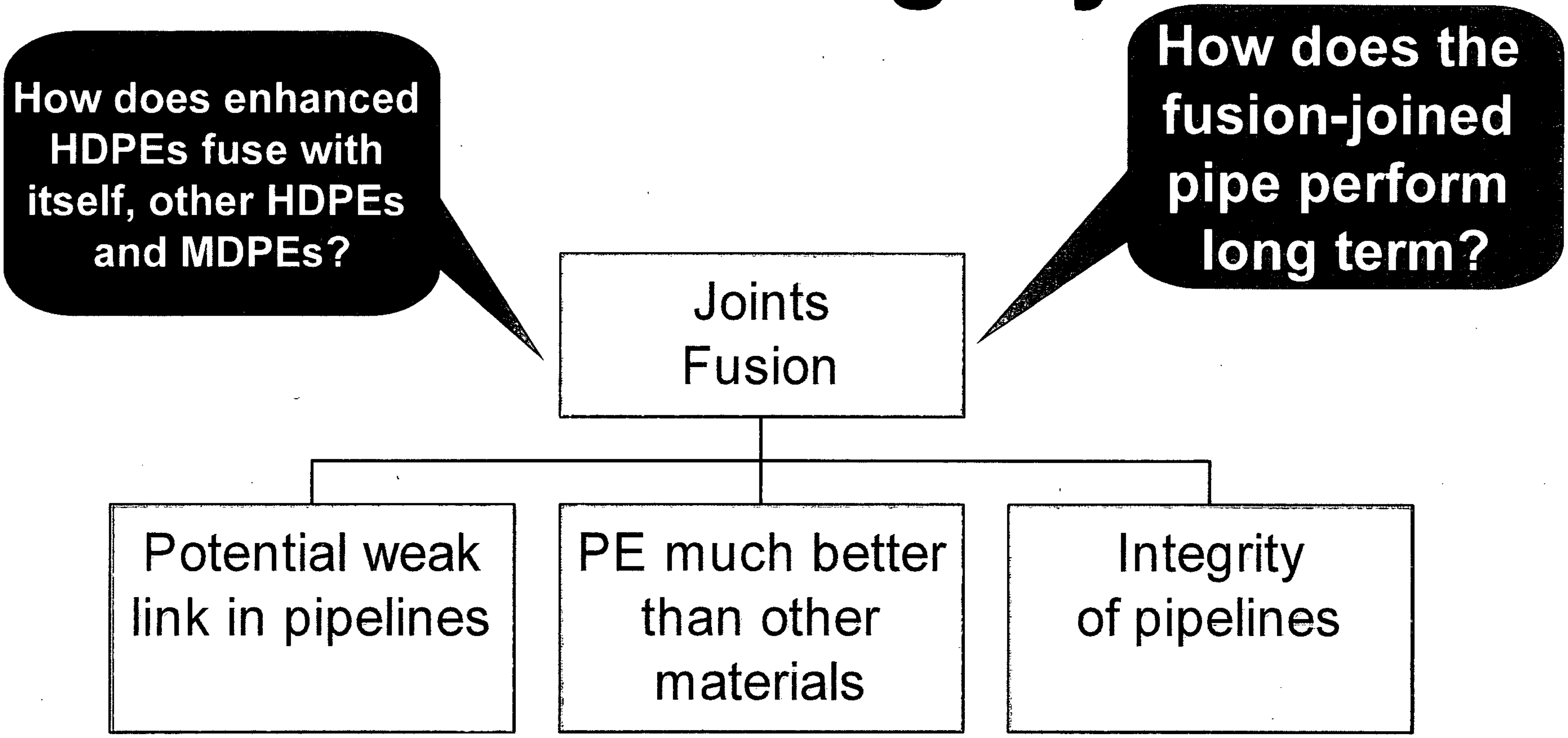
Rapid Crack Propagation (RCP)

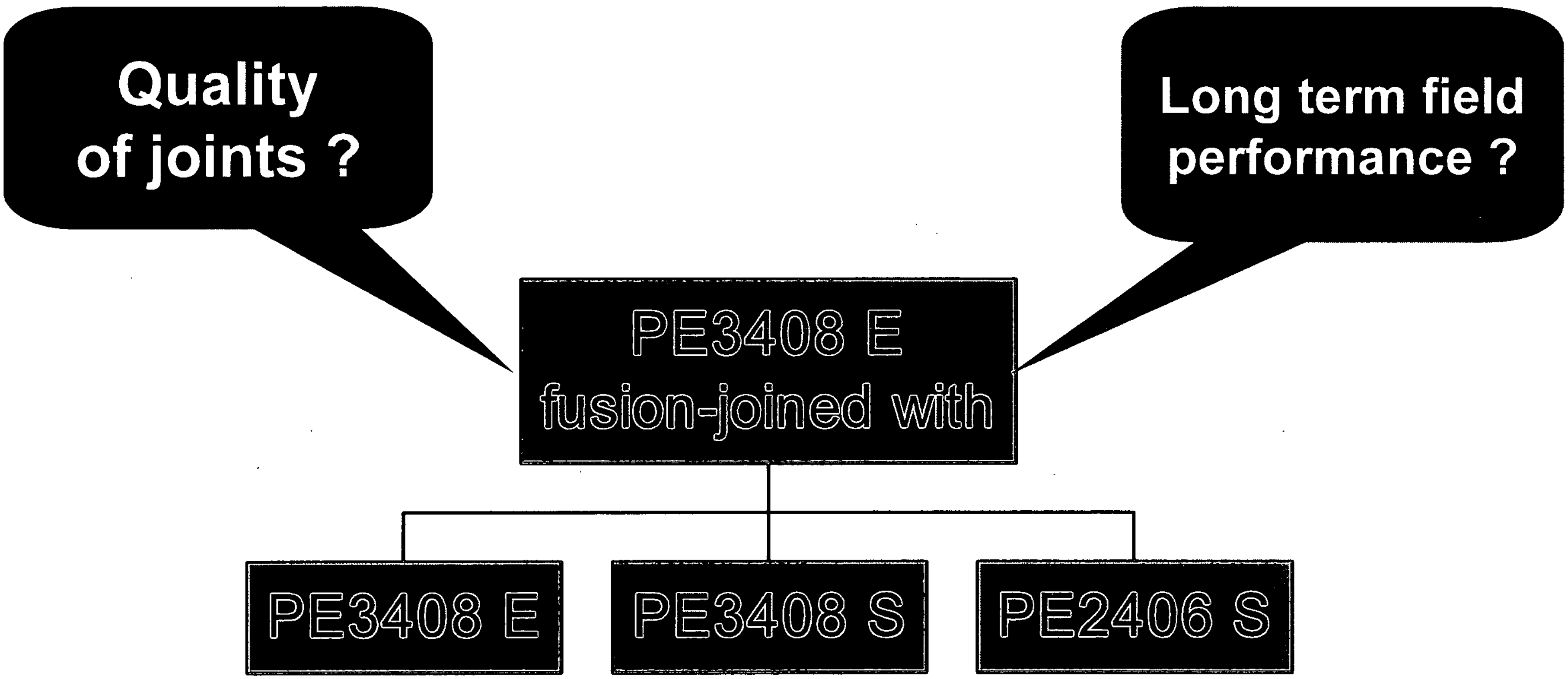
Samples	Material Designation	Tc, °C	Pc, bar	Pc, bar
		ISO 13477	ISO 4437	ISO 13477
PE2406C	PE2406	18 – 33		
PE2406S	PE2406	18 – 33		
PE3408S	PE3408	9 –19		
PE3408E	**PE3408**	**< -17**		**>12**
PE100S	PE100		4.2	>10
PE100E	**PE100**	**< -17**	**4.2**	**>12**

PE3408 E is significantly better than other HDB-rated materials; RCP is impossible above -17°C

Joint Integrity

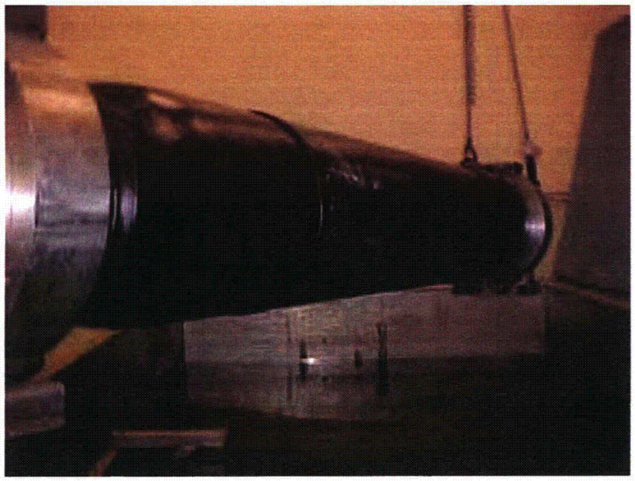


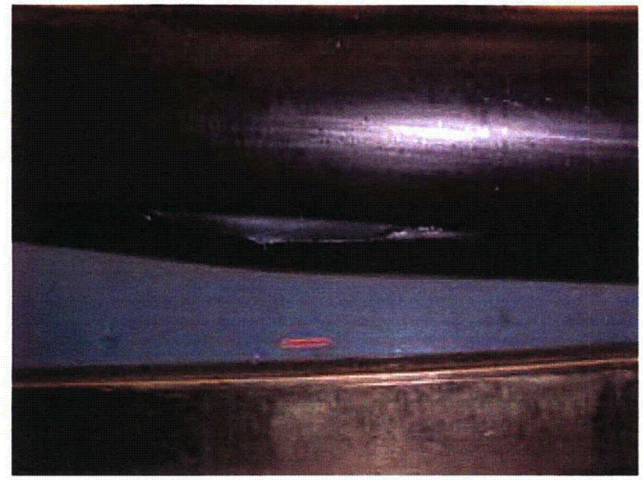
Fusion Joints



PE100 E Quick Burst Test

22" SDR 9 Butt-fusion Joined Pipe





Pipe Sample	PE100E
Pipe Outside Diameter, inches	22.025
Minimum Wall Thickness, inches	2.496
Test Condition	23°C
Internal Pressure, psig	1090
Hoop Stress, psi	4264

69% higher than the requirement, 2520 psi, for PE3408

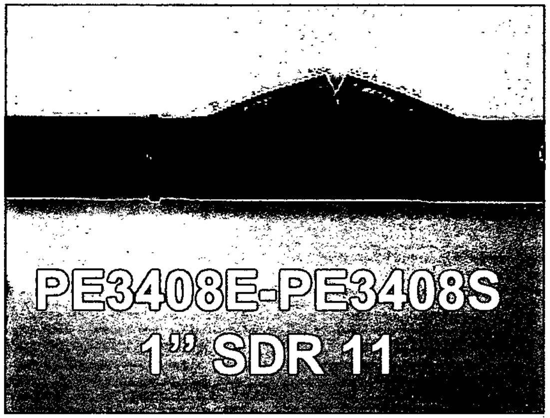
PE3408E Quick Burst Test

20" SDR 11 Butt-fusion Joined Pipe

Pipe Sample	PE3408E
Pipe Outside Diameter, inches	20.0
Minimum Wall Thickness, inches	1.81
Test Condition	23°C
Internal Pressure, psig	900
Hoop Stress, psi	4522

79% higher than the requirement, 2520 psi, for PE3408

Hydrostatic Test: HDPE



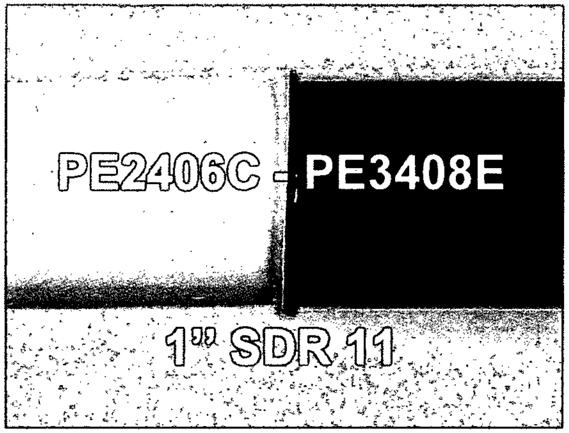
Better Joints
Ductile: 4 times and all failures in PE3408S
Brittle: >5 times; failed in joints
Cross fusion: 28%

Hydrostatic Test	Failure Times, hours		
	PE3408E-PE3408E	PE3408S-PE3408S	PE3408E-PE3408S
23°C, 1800 psi	254/D	67/D	61/D
%	379	Reference	
80°C, 800 psi	1000/NF	204/B	261/B
%	>491	Reference	128

Check Ductile

Check Brittle
1h@80C = 100h@23C

Hydrostatic Test: MDPE



Better Joints
All failed in PE2406C
23C: >2 times;
80C: >19 times;
Cross fusion: stronger than PE2406C

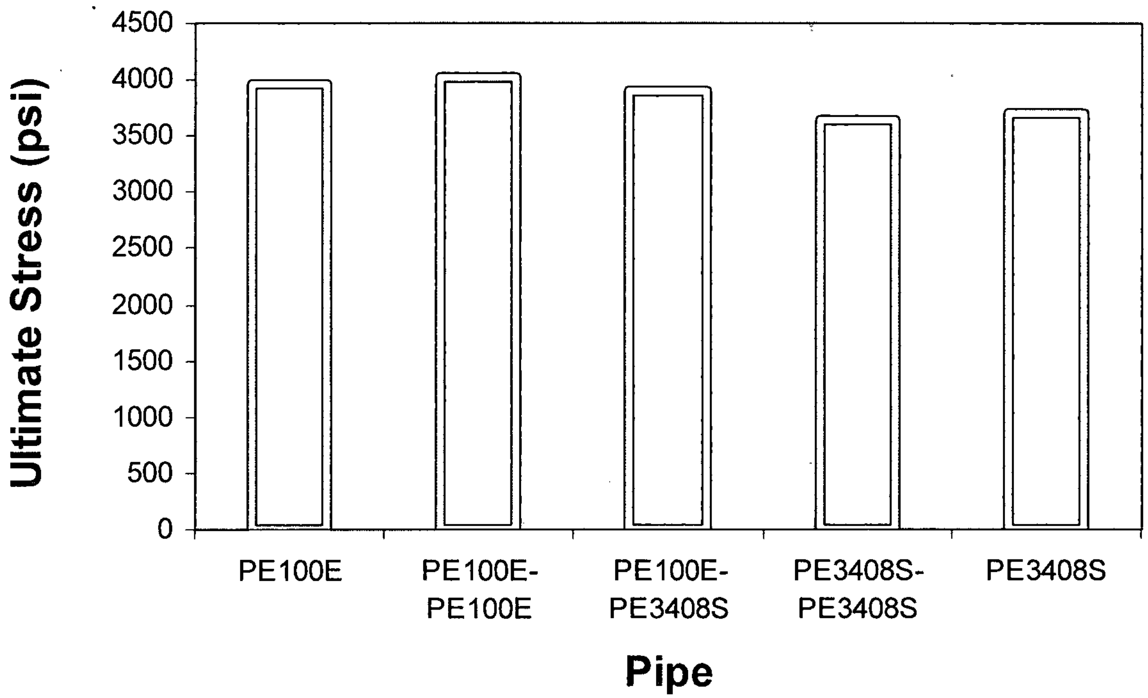
Hydrostatic Test	Failure Time, hrs		
	PE3408E-PE3408E	PE2406C-PE2406C	PE3408E-PE2406C
23C, 1600 psi	140/NF	69/D	63/D
%	>203	reference	
80C, 800 psi	1100/NF	0.58/D	1.3/D
%	>1900	reference	

Check Ductile

Check Brittle
1h@80C = 100h@23C

McSnapper™: PE100E and PE3408S

8" SDR 11 Butt-fusion Joined Pipe



ASTM D638
Easy pass

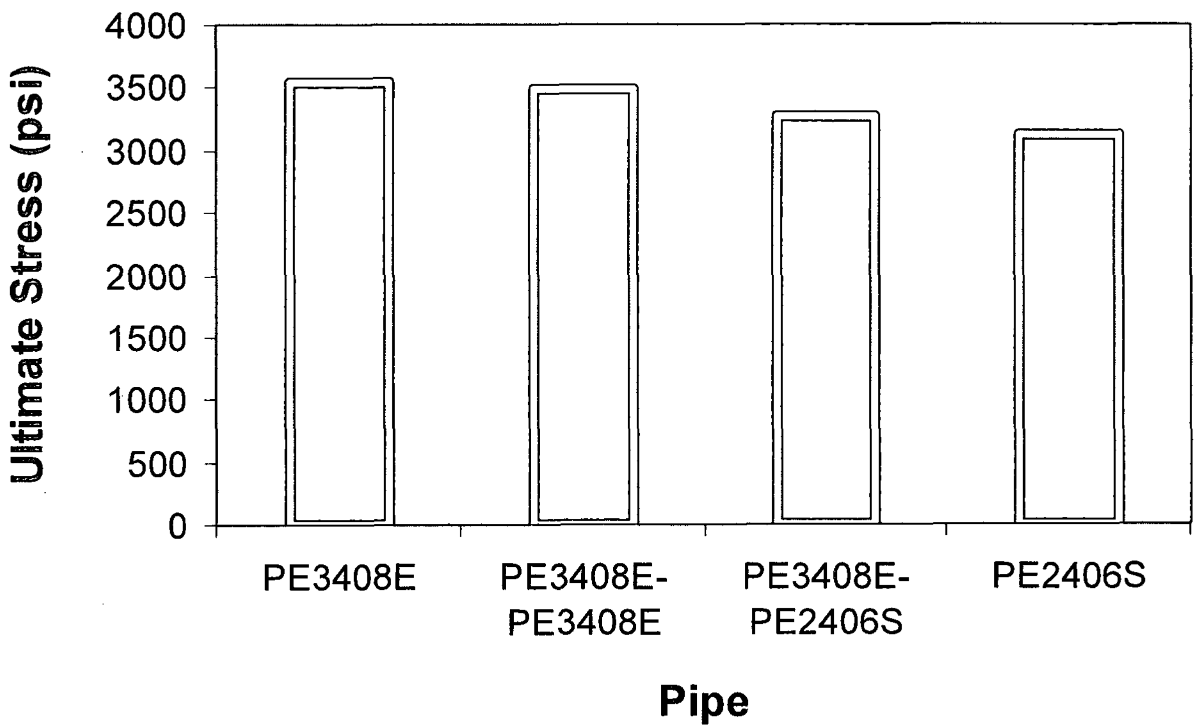
McSnapper:

High speed tensile impact

No brittle failure

McSnapper™: PE3408E and PE2406S

2" SDR 11 Butt-fusion Joined Pipe



DOW

Summary: HDB-rated Materials

- PE3408E
  - Improved safety, durability and efficiency;
  - Higher MOP from 23°C to 60°C;
  - Much better SCG resistance;
  - Much better RCP resistance;
  - High quality improved butt-fusion joints with itself, other PE3408 and PE2406;
  - DOW DGDC-2480 BK 3408 is the enhanced PE3408

Summary: MRS-rated Materials

- PE100E
  - Improved safety, durability and efficiency;
  - MRS listing for 100 years at 20°C and at elevated temperature;
  - Higher MOP than all HDB-rated materials;
  - Better SCG and RCP resistance than HDB-rated materials;
  - High quality improved butt-fusion joints with itself, other PE3408 and PE2406
  - DOW DGDA-2490 BK 100 is the enhanced PE100

Thank You for Your Attention

- Questions?

Enclosure 4

Callaway Calculation No. 2007-13241

ISSUE SUMMARY
Form SOP-0402-07, Revision 7B

DESIGN CONTROL SUMMARY

CLIENT:	AmerenUE	UNIT NO.: 1	Page No.: 1 (of 14)
PROJECT NAME:	**Callaway Nuclear Plant**		
PROJECT NO.:	11504-021	☒ NUCLEAR SAFETY- RELATED	
CALC. NO.:	2007-13241	☐ NOT NUCLEAR SAFETY-RELATED	
TITLE:	Minimum Wall Thickness for ESW Buried HDPE Piping		
EQUIPMENT NO.:			

IDENTIFICATION OF PAGES ADDED/REVISED/SUPERSEDED/VOIDED & REVIEW METHOD

INITIAL ISSUE

See Limitations in Section 6.3

INPUTS/ ASSUMPTIONS
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NOTE: PRINT AND SIGN IN THE SIGNATURE AREAS

TABLE OF CONTENTS

1.0 PURPOSE AND SCOPE

The purpose of this calculation is to determine the minimum required wall thickness for the Callaway Nuclear Plant ESW buried High Density Polyethylene (HDPE) supply, return, and strainer backwash straight piping that is to replace the currently existing buried carbon steel piping under modification number MP 07-0066 [Ref. 7.2.1]. This calculation does not apply to fittings and components.

Specifically, this calculation applies to the following line numbers:

EF-002-HBC-4" - ESW Train 'A' Strainer Backwash Line
EF-003-HBC-30" - ESW Train 'A' Supply from ESW Pumphouse
EF-006-HBC-4" - ESW Train 'B' Strainer Backwash Line
EF-007-HBC-30" - ESW Train 'B' Supply from ESW Pumphouse
EF-083-HBC-30" - ESW Train 'A' Return to UHS Cooling Tower
EF-140-HBC-30" - ESW Train 'B' Return to UHS Cooling Tower

Note: As a result of the replacements performed under modification number MP 07-0066 [Ref. 7.2.1], the material designation code (HBC) as defined by MS-02 [Ref. 7.2.7] will change for the replaced sections of the above lines.

2.0 DESIGN INPUTS

2.1 ESW HDPE Supply Lines

Internal design pressure (P_D) = 165 psig [Ref. 7.2.1]

Design temperature (T_D) = 95°F [Ref. 7.2.1]

Outside diameter of pipe (D) = 36″ [Ref. 7.2.1]

Piping Material: PE 4710 with material properties not less than those for cell classification 445574C as defined by ASTM D3350 [Ref. 7.2.1]

2.2 ESW HDPE Return Lines

Internal design pressure (P_D) = 45 psig [Ref. 7.2.1]

Design temperature (T_D) = 175°F [Ref. 7.2.1]

Normal Operating Temperature (T_o) = 105°F [Ref. 7.2.8]

Outside diameter of pipe (D) = 36″ [Ref. 7.2.1]

Piping Material: PE 4710 with material properties not less than those for cell classification 445574C as defined by ASTM D3350 [Ref. 7.2.1]

2.3 ESW HDPE Backwash Lines

Internal design pressure (P_D) = 160 psig [Ref. 7.2.1]

Design temperature (T_D) = 95°F [Ref. 7.2.1]

Outside diameter of pipe (D) = 4.5″ [Ref. 7.2.1]

Piping Material: PE 4710 with material properties not less than those for cell classification 445574C as defined by ASTM D3350 [Ref. 7.2.1]

2.4 Design Code

The design code for the HDPE piping is ASME Code Case N-755 "Use of Polyethylene (PE) Plastic Pipe for Section III, Division I, Construction and Section XI Repair/Replacement Activities" [Ref. 7.1.1] per modification number MP 07-0066 [Ref. 7.2.1].

2.5 Mechanical and Erosion Allowance

No mechanical or erosion allowance (C) is considered in the minimum wall thickness calculation (See Assumption 3.1) [Ref. 7.2.4, p. 8].

2.6 Normal Service Life

The replacement buried piping shall be designed for a service life of 40 years under normal system operating conditions as stated in Reference 7.2.2, Section 6.1.1.

2.7 Post-Accident Service Life

The replacement buried piping shall be designed for a service life of 30 days at peak post-accident system operating conditions. The design shall assume that the peak post-accident conditions occur continuously for the entire 30 day period and that the accident occurs at the end of the 40 year normal service life as stated in Reference 7.2.2, Section 6.1.2.

2.8 Allowable Stress

Allowable stress values for HDPE must be based on values determined through testing at conditions that bound the design conditions of the replacement buried piping and formally accepted for use at Callaway Nuclear Plant by the Nuclear Regulatory Commission as stated in Reference 7.2.2, Section 6.9. The following values are used within this calculation based on direction provided in Reference 7.2.5. The use of these values for Callaway Nuclear Plant still requires formal acceptance by the NRC (Limitation 6.3.1).

Table 2.8-1 – Allowable Stress

Service Temp. (°F)	Load Duration (yrs)	Allowable Stress (psi)
95°F	≤ 50	695
104°F	≤ 50	653
113°F	≤ 50	613
176°F	2.5	340

Note: While Reference 7.2.5 only provides values for a load duration of 50 years, these values can conservatively be used for load durations of less than 50 years.

3.0 ASSUMPTIONS

3.1 **Assumption**: No mechanical or erosion allowance (C) is considered in the minimum wall thickness calculation.

Justification:
HDPE pipe will not rust, rot, pit, corrode, tuberculate or support biological growth. It has superb chemical resistance and is the material of choice for many harsh chemical environments [Ref. 7.2.4, p. 8]. Therefore, no mechanical or erosion allowance is required. This is consistent with Reference 7.2.2, Section 6.2.

3.2 **Assumption**: The allowable stress value for the HDPE Return Lines for a post-accident condition service life of 30 days is 340 psi at 175°F.

Justification:
The only allowable stress value data available near 175°F is 340 psi at 176°F for a load duration of 2.5 years in Reference 7.2.5 [Design Input 2.8]. The allowable stress for 2.5 years is lower than the allowable stress for 30 days and the allowable stress at 176°F is lower than the allowable stress at 175°F. This will result in a larger minimum wall thickness for the 30 day post-accident condition service life case at 175°F for the HDPE Return Lines. Therefore, it is conservative to use 340 psi.

4.0 METHODOLOGY AND ACCEPTANCE CRITERIA

4.1 Methodology

4.2 Allowable Stress for HDPE Return Lines

Since the allowable stress value at a design temperature of 175°F for the HDPE Return Lines has only been provided for a maximum load duration of 2.5 years in Reference 7.2.5, an allowable stress value is calculated for the Normal Operating Condition case as defined by Miner's Rule using the methodology in Sections 4.2.1 and 4.2.2 and 340 psi for the 30 day Post-Accident Condition case (See Assumption 3.2). A minimum wall thickness will be calculated for both the Normal Operating Condition and the 30 day Post-Accident Condition and the larger of the two shall be conservatively used for the HDPE Return Lines.

4.2.1 Miner's Rule to Calculate Load Duration

Miner's Rule takes into consideration the damages done to the pipe under different operating conditions to calculate the cumulative maximum permissible time of use under all varying conditions of the pipe. For the HDPE return lines, Normal Operating Conditions and Post-Accident Operating Conditions are considered. The cumulative maximum permissible time of use is the design service life of 40 years.

To calculate the allowable stress value for Normal Operating Conditions, Miner's Rule for plastic pipe [Ref. 7.2.6] is used to find the load duration for the pipe under normal operating conditions that will ensure a cumulative maximum permissible time of use of 40 years when considering the 30 day load duration at Post-Accident Operating Conditions. This load duration can then be used to interpolate a corresponding allowable stress value using the values in Reference 7.2.5 at the normal operating temperature of 105°F. The allowable stress value for a load duration of ≤ 50 years at 105°F is provided in Reference 7.2.5 [Design Input 2.8]. The following variables are used by Miner's Rule:

T_o = normal operating temperature (°F)
T_{max} = maximum operating temperature (post-accident temperature) (°F)
A_i = percent of total service life of pipe under condition "i" (i=1, 2, 3, etc.) (%)
t_i = lifetime of pipe if placed under condition "i" (yrs)
t_{max} = lifetime of pipe if placed under maximum operating temperature T_{max} (yrs)
t_o = lifetime of pipe if placed under normal operating temperature T_o (yrs)
t_x = maximum permissible time of use under all varying conditions (yrs)
TYD = total yearly damage (%)

The percent of total service life of the pipe under each condition "i" is calculated for i=1, 2, 3, etc.

$$A_i = \frac{\text{Time Under Condition "i" (yrs)}}{\text{Total Service Life of Pipe (yrs)}}$$

Each condition which the pipe is exposed to generates a yearly damage percentage on the pipe.

$$\text{Yearly Damage} = \frac{A_i}{t_i} = \frac{\text{Time Under Condition "i" (yrs)}}{\text{Lifetime of Pipe Under Condition "i" (yrs)}}$$

The summation of these yearly damages is the total yearly damage.

$$TYD = \sum \frac{A_i}{t_i}$$

The total yearly damage (TYD) is used to find the maximum permissible time of use under all varying conditions.

$$t_x = \frac{100}{TYD}$$

To find the load duration for the pipe under normal operation, Miner's Rule is rearranged to solve for t_o, the lifetime of pipe if placed under only the normal operating temperature T_o = 105°F. This duration will be longer than t_x, the maximum permissible time of use under all varying conditions, and will provide a lower allowable stress value. Therefore, the minimum wall thickness calculated using this value for allowable stress for Normal Operating Conditions will result in a larger minimum wall thickness which is conservative.

First, solve for the percent of the total service life of the pipe that is exposed to the normal operating temperature and the post-accident temperature to obtain A_o and A_{max} respectively. Then calculate the yearly damage percentages on the pipe from the Normal Operating and Post-Accident Condition where t_o is the unknown variable to solve for and t_{max} is 2.5 years as stated in Assumption 3.2.

$$\text{yearly damage from post-accident condition} = \frac{A_{max}}{t_{max}}$$

$$\text{yearly damage from normal operating condition} = \frac{A_o}{t_o}$$

Summate the yearly damages to obtain the total yearly damage as a function of t_o.

$$TYD = \sum \frac{A_i}{t_i} = \frac{A_o}{t_o} + \frac{A_{max}}{t_{max}}$$

With the maximum permissible time of use under all varying conditions set as 40 years, t_x = 40 years, substitute the TYD and solve for t_o.

$$t_x = \frac{100}{TYD} \rightarrow 40 = \frac{100}{\frac{A_o}{t_o} + \frac{A_{max}}{t_{max}}}$$

4.2.2 Interpolation for Allowable Stress Values for Normal Operating Condition Case of the HDPE Return Lines Using the Calculated Load Duration (t_o)

To determine the allowable stress values for the Normal Operating Condition case, interpolate between the load durations of 50 years and the calculated t_o load duration.

4.3 Minimum Wall Thickness

The required minimum wall thickness is determined for the pipe lines identified in Section 1.0 of this calculation. The required minimum wall thickness (t_{design}) is calculated in accordance with ASME Code Case N-755 [Ref. 7.1.1, Section 3021.1] as follows:

$$t_{design} = \underbrace{\frac{P_D D}{2S + P_D}}_{t_{min}} + C$$

where:

t_{design} = minimum required wall thickness (in)
t_{min} = pressure design thickness (in)
C = the sum of mechanical allowances and erosion allowance (in)
P_D = piping system internal Design Pressure (gage) at the corresponding Design Temperature T_D. This pressure does not include the consideration of pressure spikes due to transients (psig)
D = pipe outside diameter at the pipe section where the evaluation is conducted (in)
S = allowable stress (psi)

4.4 Acceptance Criteria

None

5.0 CALCULATIONS

5.1 Calculation of Normal and Post-Accident Condition Allowable Stresses Values for HDPE Return Lines

5.1.1 Percent of total service life of the pipe under each condition.

$$A_o = \frac{40years - 30days(post\text{-}accident) = 39.92years}{40years} x100\% = 99.8\%$$

$$A_{max} = \frac{30days(post\text{-}accident) = 0.08years}{40years} x100\% = 0.2\%$$

5.1.2 Summate the yearly damages to obtain the total yearly damage as a function of t_o.

$$TYD = \sum \frac{A_i}{t_i} = \frac{99.8\%}{t_o} + \frac{0.2\%}{2.5years}$$

5.1.3 Substitute the TYD and solve for t_o.

$$t_x = \frac{100}{TYD} \rightarrow 40years = \frac{100}{\frac{99.8\%}{t_o} + \frac{0.2\%}{2.5years}} \Rightarrow t_o = 41.2\ years$$

5.1.4 Interpolate between temperatures of 113°F and 104°F to find the allowable stress value $S_{105°F}$ at 105°F and 50 years from Design Input 2.8.

$$S_{105°F} = \frac{(613\ psi - 653\ psi)}{(113°F - 104°F)}(105°F - 104°F) + 653\ psi = 648.6\ psi$$

5.1.5 Interpolate between the load durations of 50 and 40 years to find the correlating t_o load duration allowable stress at 105°F [Design Input 2.8].

$$S_{t_o,105°F} = \frac{(648.6\ psi - 648.6\ psi)}{(50yrs - 40yrs)}(41.2yrs - 40yrs) + 648.6\ psi = 648.6\ psi$$

Table 5.1.5-1 – HDPE Return Line Normal Operation Allowable Stress

	Load Duration		
	40 yrs	t_o = 41.2 yrs	50 yrs
Allowable Stress (S) (psi)	$S_{t_x,105°F}$ = 648.6	$S_{t_o,105°F}$ = 648.6	$S_{105°F}$ = 648.6

Table 5.1.5-2 – HDPE Return Line Post-Accident Allowable Stress

(See Assumption 3.2)	**Load Duration**
	30 days
Allowable Stress (S) (psi)	$S_{175°F}$ = 340

5.2 Minimum Calculated Wall Thicknesses

5.2.1 Supply Lines

Under an internal design pressure of 165 psig (Design Input 2.1), design temperature of 95°F (Design Input 2.1), mechanical and erosion allowance of 0" (Design Input 2.5), and allowable stress of 695 psi (Table 2.8-1) for both supply lines, the PE 4710 36″ diameter ESW HDPE supply line piping minimum required wall thickness is:

$$t_{\text{design, supply}} = \frac{(165\text{psig})(36'')}{2(695\text{psi}) + 165\text{psig}} + 0 = 3.82''$$

5.2.2 Return Lines

5.2.2.1 For the Normal Operating Conditions case, an internal design pressure of 45 psig (Design Input 2.2), design temperature of 105°F (Design Input 2.2), mechanical and erosion allowance of 0" (Design Input 2.5), and allowable stress of 648.6 psi (Table 5.1.5-1) for both return lines, the PE 4710 36″ diameter ESW HDPE return line piping minimum required wall thickness is:

$$t_{\text{design, return, normal op.}} = \frac{(45\text{psig})(36'')}{2(648.6\text{psi}) + 45\text{psig}} + 0 = 1.21''$$

5.2.2.2 For the Post-Accident Conditions case, an internal design pressure of 45 psig (Design Input 2.2), design temperature of 175°F (Design Input 2.2), mechanical and erosion allowance of 0" (Design Input 2.5), and allowable stress of 340 psi (Table 5.1.5-2) for both return lines, the PE 4710 36″ diameter ESW HDPE return line piping minimum required wall thickness is:

$$t_{\text{design, return, post-accident}} = \frac{(45\text{psig})(36'')}{2(340\text{psi}) + 45\text{psig}} + 0 = 2.235'' = \text{bounding minimum wall value}$$

5.2.3 Backwash Lines

Under an internal design pressure of 160 psig (Design Input 2.3) and design temperature of 95°F (Design Input 2.3), mechanical and erosion allowance of 0" (Design Input 2.5), and allowable stress of 695 psi (Table 2.8-1) for both backwash lines, the PE 4710 4.5″ diameter ESW HDPE backwash line piping minimum required wall thickness is:

$$t_{\text{design, backwash}} = \frac{(160\text{psig})(4.5'')}{2(695\text{psi}) + 160\text{psig}} + 0 = 0.465''$$

6.0 RESULTS

6.1 Results

The required minimum wall thicknesses for the ESW buried HDPE pipes are shown below in Table 6.1-1:

Table 6.1-1 - Summary of Results

Line No.	Min. Wall Thickness (in)
EF-003-HBC-30" - ESW Train 'A' Supply from ESW Pumphouse	3.82"
EF-007-HBC-30" - ESW Train 'B' Supply from ESW Pumphouse	3.82"
EF-083-HBC-30" - ESW Train 'A' Return to UHS Cooling Tower	2.235"
EF-140-HBC-30" - ESW Train 'B' Return to UHS Cooling Tower	2.235"
EF-002-HBC-4" - ESW Train 'A' Strainer Backwash Line	0.465"
EF-006-HBC-4" - ESW Train 'B' Strainer Backwash Line	0.465"

Note: As a result of the replacements performed under modification number MP 07-0066 [Ref. 7.2.1], the material designation code (HBC) as defined by MS-02 [Ref. 7.2.7] will change for the replaced sections of the above lines.

6.2 Conclusions

The required minimum calculated wall thickness values provided in Section 6.1 of this calculation apply to straight pipe only and include 0.0" mechanical and erosion allowance. Nominal wall thickness values for the applicable lines must account for manufacturing tolerances such that the as-manufactured minimum wall thickness values for the piping are greater than or equal to the required values.

6.3 Limitations

6.3.1 The allowable stress values used within this calculation are based on values provided in Reference 7.2.5. The use of these values for Callaway Nuclear Plant still requires formal acceptance by the NRC.

6.3.2 This calculation uses Miner's Rule methodology as defined in Reference 7.2.6. The use of this methodology for Callaway Nuclear Plant still requires formal acceptance by the NRC.

6.4 Impact Assessment

The following sections identify the documents reviewed for impact by this calculation and summarize the results of the impact assessments. Impacts as a result of the piping replacement being performed under MP 07-0066 are identified and evaluated as part of MP 07-0066.

6.4.1 FSAR / Site Addendum

The following sections of the standard plant FSAR and site addendum were reviewed for impact by this calculation:

3.9(B) (SP): Minimum wall thickness is not discussed in the FSAR for the design of non-NSSS piping. (NOT IMPACTED)

9.2 (SP and SA): This calculation does not change the design basis functions of the ESW system, design conditions of the ESW piping or design heat loads acting on the ESW system. (NOT IMPACTED)

6.4.2 Technical Specifications / Technical Specification Bases

The following sections of the technical specifications and technical specification bases were reviewed for impact by this calculation:

3.7.8 / B 3.7.8: This calculation does not change any surveillance requirements for the ESW system. None of the bases for the surveillance requirements are impacted. (NOT IMPACTED)

6.4.3 Other Documents

MS-02: A new material designation must be added to MS-02 for HDPE. This material designation must ensure that the nominal wall thickness values of installed HDPE piping will provide actual minimum wall thickness values greater than or equal to the required minimum wall thickness values determined in this calculation. (IMPACTED)

6.4.4 Design and Operating Margins

This calculation determines required minimum wall thickness for the subject replacement ESW piping. The nominal wall thickness of the installed piping, and hence the margin between the as-manufactured minimum wall thickness and the required minimum wall thickness, will be identified by MP 07-0066.

7.0 REFERENCES

7.1 Codes

7.1.1 ASME Code Case N-755, "Use of Polyethylene (PE) Plastic Pipe for Section III, Division 1, Construction and Section XI Repair/Replacement Activities", as approved by the Board on Nuclear Codes and Standards on 03/22/2007 (Prior to incorporation of ASME Editor changes made in PDF Release)

7.2 Miscellaneous

7.2.1 Callaway Nuclear Plant Modification No. MP 07-0066, "Replace Buried ESW Piping with HDPE Material"

7.2.2 Callaway Nuclear Plant Design Specification No. M-2017, Rev.0, "Design Specification for Replacement ASME Section III Buried Essential Service Water System Piping"

7.2.3 S&L Calculation 2007-11380, Rev. 1, "Determination of Peak ESW Buried Piping Operating Conditions"

7.2.4 The Plastics Pipe Institute, Inc. "Handbook of Polyethylene Pipe", First Edition

7.2.5 Letter NEMM 07-0038 from Matt Brandes (AmerenUE) to Mr. Musto (Sargent & Lundy, LLC) dated 11/30/2007, "Design Inputs for Development of MP 07-0066, ESW Buried Piping Replacement" **(See Limitation 6.3.1)**

7.2.6 The International Organization for Standardization, ISO 13760:1998(E), "Plastics Pipes for the Conveyance of Fluids Under Pressure – Miner's Rule – Calculation Method for Cumulative Damage" **(See Limitation 6.3.2)**

7.2.7 Callaway Nuclear Plant Drawing MS-02, Rev. 83, "Piping Class Sheets"

7.2.8 Callaway Nuclear Plant Document MS-01, Rev. 96, "Piping Class Summary"

8.0 ATTACHMENTS

1. Letter NEMM 07-0038 from Matt Brandes (AmerenUE) to Mr. Musto (Sargent & Lundy, LLC) dated 11/30/2007, "Design Inputs for Development of MP 07-0066, ESW Buried Piping Replacement" — 3 Pages

2. AmerenUE Owner's Review Comments — Later

Attachment 1

Letter NEMM 07-0038 from Matt Brandes (AmerenUE) to Mr. Musto (Sargent & Lundy, LLC) dated 11/30/2007, "Design Inputs for Development of MP 07-0066, ESW Buried Piping Replacement"

AmerenUE
Callaway Plant

PO Box 620
Fulton, MO 65251

NEMM 07-0038
November 30, 2007

Mr. Thomas M. Musto
Senior Associate
Sargent & Lundy, LLC
55 East Monroe St.
Chicago, IL 60603

Subject: Design Inputs for Development of MP 07-0066, ESW Buried Piping Replacement

Reference: 1. MP 07-0066, "Replace Buried ESW Piping with HDPE Material"

Ameren UE

Dear Mr. Musto:

Sargent and Lundy (S&L) have requested that Ameren UE provide the following information as design inputs for development of Reference 1. The design inputs that are requested are:

1. Stress allowables for the high density polyethylene (HDPE) piping at temperatures above those currently provided in ASME Code Case N-755.
2. Elastic modulus values for the HDPE piping at temperatures above those currently provided in ASME Code Case N-755.

The information requested is being transmitted in the attachments to this letter.

For item 1, the stress allowables for HDPE provided by this transmittal are equivalent to the tables currently being added to the planned revision of Code Case N-755 (i.e. Revision 1), which is under review of ASME. During the ASME code committee meeting in November 2007, the issue of design factor was discussed. Although the ASME may yet approve a design factor greater than 0.5, for the scope of MP 07-0066, a design factor of 0.5 should be used.

For item 2, the elastic modulus to be used is table 3031-3 in ASME Code Case N-755, "Use of Polyethylene (PE) Plastic Pipe for Section III, Division 1, Construction and Section XI Repair/Replacement Activities", as approved by BPV Standards Committee 02/02/2007". This table is equivalent to Table 3210-3 in the current Code Case N-755 Rev. 0. Based on discussion with Frank Schaaf and Bill Adams (WL Plastics), the use of the elastic modulus values at 140°F for temperatures higher than those currently provided in ASME Code Case N-755 (i.e. >140°F) is conservative for thermal expansion and contraction stress calculations. For ring deflection and buckling due to external pressure, a minimum elastic modulus of 2 ksi for temperatures less than or equal to 176°F can be used for the PE 4710 material. Industry testing is currently being performed to determine actual values. However, based on linear extrapolation of the data in Code Case N-755, the actual value is expected to be higher. Therefore, the use of a value of 2 ksi is expected to be conservative.

Sincerely,

Matt Brandes

Matt Brandes

Attachment

cc: S. L. Abel
J. E. O'Sullivan
A160.2001

NEMM070038 Attachment 1

Table 3021-1 Allowable Design Stress, S, for PE4710 (Dow DGDA-2490/2492)* (psi)

Service Temperature °F (°C)	Load Duration					
	2.5 Years			50 Years**		
	0.50 DF	0.56 DF	0.63 DF	0.50 DF	0.56 DF	0.63 DF
73 (23)	Not Applicable			800	889	1000
86 (30)	Not Applicable			738	826	929
95 (35)	Not Applicable			695	778	875
104 (40)	Not Applicable			653	732	823
113 (45)	Not Applicable			613	687	773
122 (50)	Not Applicable			574	643	724
131 (55)	Not Applicable			537	601	676
140 (60)	Not Applicable			500	560	630
176 (80)	340	382	430	Not Applicable		

* Values not applicable to all materials.
** For service temperature 140°F (60°C), use 50-year allowable design stress for service life 50-years.

Attachment 2

AmerenUE Owner's Review Comments

Enclosure 5

AmerenUE

Callaway Nuclear Plant

10 CFR 50.55a Request Number I3R-10

Proposed Alternative to ASME Section XI Requirements for Replacement of Class 3 Buried Piping in Accordance with 10 CFR 50.55a(a)(3)(i)

(Includes attachment, "Requirements for HDPE Piping for Nuclear Service," dated July 10, 2008)

10 CFR 50.55a Request Number I3R-10

1.ASME Code Component(s) Affected

ASME Class 3 buried Essential Service Water (ESW) System piping.

2. Applicable Code Edition and Addenda

ASME Boiler and Pressure Vessel Code, Section XI, Division 1, 1998 Edition through 2000 Addenda.

3. Applicable Code Requirement

ASME Section XI, IWA-4221(b) requires that "an item to be used for repair / replacement activities shall meet the Construction Code specified in accordance with (l), (2), or (3) [of IWA-4221(b)]", and ASME Section XI, IWA-4221(b)(l) requires that "when replacing an existing item, the new item shall meet the Construction Code to which the original item was constructed."

4. Reason for Request

A modification has been proposed for Callaway in which the underground steel piping of the ESW system would be replaced with piping made from high-density polyethylene (HDPE).

The Construction Code of record for buried ASME Class 3 ESW piping is ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection ND, 1974 Edition, through Summer 1975 Addenda. This Construction Code and later editions and addenda of this Construction Code do not provide rules for the materials, design, fabrication, installation, examination and testing of piping constructed with polyethylene material.

Therefore, this request is being submitted to allow the replacement of buried steel piping in the Callaway ESW system with polyethylene piping. The replacement will be in accordance with the attached document, "Requirements for HDPE Piping for Nuclear Service," dated July 10, 2008.

5. Proposed Alternative and Basis for Use

The attached document, "Requirements for HDPE Piping for Nuclear Service," dated July 10, 2008 provides the requirements for material, design, fabrication, installation, examination and testing of high density polyethylene piping, and reflects an acceptable level of quality and safety for repair / replacement activities for ASME Section III, Division 1 Class 3 buried piping.

The Callaway ESW system was originally designed with unlined carbon steel piping. Plant specific and industry operating experience has shown that carbon steel piping is susceptible to fouling, corrosion, and microbiologically induced corrosion (MIC) for raw water applications.

The use of corrosion resistant steel piping provides added resistance to these problems, but does not eliminate susceptibility. Alternatively, the use of internal linings or coatings in carbon steel piping provides resistance to these problems. However, degradation of and/or damage to the linings and coatings can cause exposure of the carbon steel piping to the raw water, resulting in piping degradation. Additionally, the linings and coatings can pose a potential foreign material concern if they are released from the piping wall as a result of the degradation or damage.

Polyethylene piping pipe will not rust, rot, pit, corrode, tuberculate, or support biological growth. The use of polyethylene piping in raw water applications will thus ensure long term reliability from a structural integrity and flow standpoint. Callaway has recently installed approximately 600 linear feet of 36-inch diameter buried polyethylene piping in a non-safety related blowdown application and has not experienced any significant problems. On a larger scale, Duke Power Company has installed 20,000 linear feet of polyethylene piping at Catawba Nuclear Station in non-safety related raw water applications. Since the installations began in 1998, Duke Power Company has reported that the material has had an excellent service history and has not experienced fouling or corrosion.

The use of polyethylene piping in accordance with this Relief Request will result in improved system performance and enhanced system reliability, and will provide an acceptable level of quality and safety.

6. Duration of Proposed Alternative

The use of the proposed alternative is requested for the third ten-year inservice inspection interval for Callaway.

The Callaway third ten-year inservice inspection interval is currently scheduled to end on December 18, 2014.

7. References

"Requirements for HDPE Piping for Nuclear Service," dated July 10, 2008 (attached)

TR33/2001, "Generic Butt Fusion Joining Procedure for Polyethylene Gas Pipe"

The Plastics Pipe Institute, Inc. "Handbook of Polyethylene Pipe"

Requirements for HDPE Piping for Nuclear Service

AmerenUE Callaway Plant

July 10, 2008

-1000 GENERAL REQUIREMENTS
-1100 SCOPE

(a) This document contains rules for the construction of Class 3 high density polyethylene (HDPE) pressure piping and fittings. Use of these materials is permitted only for buried Emergency Service Water Systems that are classified as ASME Section III Class 3. The design pressures and temperatures of the various lines to be replaced will be 161 psig at 95°F, 160 psig at 95 °F, or 45 psig at 175 °F, as applicable to the specific line.

(b) Terms relating to polyethylene as used in this document are defined in Supplement 1.

-1200 QUALIFICATION OF SUPPLIERS

Qualification
(a) The PE material shall be procured from a qualified supplier as follows;

(1) AmerenUE shall be responsible for surveying, qualification, and auditing of the Nonmetallic Material Manufacturer and the Nonmetallic Material Constituent Supplier based on the survey and audit results of the Nonmetallic Material Manufacturer. Alternately, AmerenUE shall audit and qualify the Nonmetallic Material Manufacturer for surveying/auditing the Nonmetallic Material Constituent Supplier as permitted by ASME Section III NCA-3125 and NCA-3820.

(a) The survey and audit of the Nonmetallic Material Manufacturer will establish the following;

1. verification process of constituent material chemistry, and

2. Quality System Program conforms to NCA- 3900.

(b) When survey and audit of the Nonmetallic Material Constituent Supplier is required, the survey and audit shall evaluate the Quality System Program and the implementation of ASTM D-3350, Standard Specification for Polyethylene Plastics Pipe and Fittings Materials.

(c) Satisfactory completion of the survey and audit will allow the Nonmetallic Material Manufacturer to supply material to AmerenUE for a period of three years. After the three year period an audit shall be performed to assure continued program maintenance.

(b) AmerenUE shall perform any of the functions required by their respective Quality Assurance Program which are not performed by the Nonmetallic Material Manufacturer. AmerenUE may elect to perform any other Quality Program functions, which would normally be the responsibility of the Nonmetallic Material Manufacturer. These functions shall be clearly defined in the AmerenUE Quality Assurance Program.

c) AmerenUE shall make all necessary provisions so that the Authorized Inspection Agency can make the inspections necessary to comply with this document.

-1210 PE Procurement Chain

(a) When the Quality System surveys/audits required by -1200 have been completed, AmerenUE shall establish a qualified HDPE supply chain.

(1) The Nonmetallic Material Constituent Supplier is the organization which manufactures and certifies the base HDPE material pellets.

(2) The Nonmetallic Material Manufacturer is the organization which manufactures, and certifies HDPE material in compliance with requirements of this document. He shall perform or shall supervise and directly control one or more of the operations which affect the HDPE material properties capable to meet the requirements of the basic material specification, and shall verify the satisfactory completion of all other requirements performed by other organizations prior to his certification.

(3) The Nonmetallic Material Supplier is an organization which supplies products of the Nonmetallic Material Manufacturer but does not perform any operations which affect the HDPE materials properties required by the basic material specification.

(4) Certification to the requirements of ASME Code Case N-755 will be considered equivalent to certification to this document.

(b) All pressure retaining HDPE material used in construction of components shall be supplied with a certified certificate of analyses for batch (CCAB) or product quality certification (PQC). These documents shall include all the results of analysis and production tests performed on the HDPE material.

(1) Nonmetallic Material Constituent Supplier - Certified Certificate of Analysis for Batch or Product Quality Certification shall include HDPE material identification, physical property test results, and melt index temperature when required by AmerenUE when the approved Nonmetallic Material Manufacturer program relies on audits and certification.

(2) Nonmetallic Material Manufacturer - Certified Analysis for Batch or Product Quality Certification shall include HDPE material identification, physical property test results

(includes all in-situ and final tests), melt index temperature, mechanical property test results, and shall certify that the product was made from virgin pellets (no scrap or regrind material). The product form shall be permanently marked.

-2000 MATERIALS
-2100 GENERAL REQUIREMENTS FOR MATERIALS
-2110 Scope

(a) All HDPE material and components shall be procured using the requirements of this document and the following additional requirements.

(1) HDPE material shall be selected from approved ASTM standards listed in Supplement 2, and shall have material properties not less than those for cell classification 445574C per ASTM D 3350-05 (PE 4710). The material may contain a color stripe with cell classification 445574E. (There is no physical difference between C and E other than color.)

(2) Only HDPE pipe, mitered elbows, and flanges of nominal size 4 NPS (DR9) and 36 NPS (DR9.5) using Carbon Black pigment shall be used.

(3) All HDPE product forms (pipe, mitered elbows, and flanges) shall conform to the ASTM Standards identified in Supplement 2, as applicable.

(b) HDPE material shall be marked in accordance with the marking requirements of the ASTM specified for the material, as applicable. If required the HDPE material shall be marked for identification purposes using a metallic paint marker or stenciling marker.

(c) All metallic materials and components shall be procured using the requirements of ASME Section III, Subsection ND.

-2200 ADDITIONAL PRODUCT FORM REQUIREMENTS

-2210 Mitered Elbows

The elbow fabricator shall be covered under the AmerenUE Quality Assurance Program. AmerenUE shall provide the services of an Authorized Nuclear Inspector. AmerenUE shall ensure the following requirements are met.

(a) All HDPE pipe material used shall comply with -2110(a)

(b) The configuration of the mitered elbow shall meet the requirements of –3022.4

(c) All fabrication processes used in the fabrication of the mitered elbow shall meet the requirements of –4000 and Supplement 9.

(d) Mitered elbows shall have the fused joints inspected and accepted in accordance with –5000.

(e) A code data report shall be used for this product form (Supplement 4). Multiple assemblies may be included on a single form.

-2220 Transition Flange

(a) The pressure rating of the transition flange shall be equal to or greater than the attached straight pipe.

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

-2300 EXAMINATION AND REPAIR OF MATERIAL

-2310 Receipt Examination

(a) All HDPE material external surfaces shall be given a visual examination prior to installation. Any indentation or flaw more than 10% of the minimum wall thickness for 4 NPS piping, and more than 7% for 36 NPS piping, regardless of wall thickness, shall be unacceptable. Additionally, for any flaw that will result in a remaining wall thickness less than the required as-fabricated minimum wall thickness per ASTM F714 shall be unacceptable unless evaluated and determined to be acceptable considering the remaining wall thickness. Lesser flaws shall be evaluated in accordance with -2320.

(b) Personnel performing the examination shall be qualified in accordance with -5000 of this document.

-2320 Repair of Material

(a) For all piping, any section with a flaw not exceeding 5% of the wall thickness and not resulting in a remaining wall thickness less than the required as-fabricated minimum wall thickness per ASTM F714 may be left as is.

(b) For all other flaws, the damaged section of pipe shall either be physically removed, or shall be repaired as follows:

(1) The depression after flaw elimination is blended uniformly into the surrounding surface with a maximum taper not to exceed 3:1 (width to height).

(2) After flaw elimination the area will be inspected by visual examination to ensure that the flaw has been removed.

(3) If elimination of the flaw reduces the thickness of the section below the minimum required design thickness, the section of piping containing the flaw shall be cut out and replaced.

(c) For flanges the following requirements shall be met;

(1) if the damaged area is in the flange section the entire flange shall be replaced, and

(2) if the damaged area is in the pipe section the section shall be removed or repaired as required by (a) and (b), above.

-3000 DESIGN

-3001 Scope

The design rules of this Section are limited to buried, high density polyethylene piping systems constructed of straight pipe, one, three and five-joint mitered elbows not exceeding 22-1/2 degrees per miter, fusion joints, and flanged connections.

-3010 Nomenclature

A = cross-section area of pipe at the pipe section where the evaluation is conducted, in^2
B_d = trench width, ft
B' = burial factor
c = the sum of mechanical allowances and erosion allowance, in
D = pipe outside diameter at the pipe section where the evaluation is conducted, in
D_{avg} = average pipe diameter in accordance with ASTM F-714
DR = dimension ratio of pipe = mean diameter divided by the minimum fabricated wall thickness = $D_{avg} / t_{fab\ min}$
E_{pipe} = modulus of elasticity of pipe, psi, Table 3031-3
E' = modulus of soil reaction, psi (Data is site specific)
E'_N = modulus of soil reaction of native soil around trench, psi (Data is site specific)
F_a = axial force due to the specified Design, Service Level A, B, C, or D applied mechanical loads, lb
F_{aC} = axial force range due thermal expansion and/or the restraint of free end displacement, lb
F_{aD} = axial force due to the non repeated anchor motion, lb
F_{aE} = axial force range due to the combined effects of seismic wave passage, seismic soil movement, and building seismic anchor motion effects, lb
F_b = upward force per unit length, lb/ft
F_S = soil support factor, Table 3031-2
f_o = ovality correction factor, Table 3033.2-1
H = height of ground cover, ft
H_{gw} = height of water table above pipe, ft
K = bedding factor = 0.1
L = deflection lag factor, 1.25 to 1.50, or 1.0 if using the soil prism pressure
i = stress intensification factor, Table 3042-1
M = resultant moment due to the specified Design, Service Level A, B, C, or D applied mechanical loads, in-lb
M_C = resultant moment range due thermal expansion and/or the restraint of free end displacement, in-lb
M_D = resultant moment due to the non repeated anchor motion, in-lb
M_E = resultant moment range due to the combined effects of seismic wave passage, seismic soil movement, and building seismic anchor motion effects, in-lb

P = internal gage pressure coincident with given service level or loading, psi
P_D= internal design gage pressure at the specified design temperature. psi
P_E = vertical soil pressure loads due to weight cover of earth, lb/ft^2
P_{hydro} = external hydrostatic pressure, equal to earth plus groundwater pressure plus surcharge load, psi
P_L = vertical soil pressure due to surcharge loads, lb/ft^2
R = buoyancy reduction factor
S = allowable stress, psi, Table 3021-1
T_D= Design Temperature, deg F
t = nominal pipe wall thickness, in
t_{design} = minimum required wall thickness, in
$t_{fab\ min}$ = minimum thickness in accordance with ASTM F-714
t_{min} = pressure design thickness, in
W_c = weight of contents (equals 0 when empty), lb/ft
W_P = weight of pipe per unit length, lb/ft (exclude weight of contained liquid to represent the worst case of an empty pipe)
W_w = weight of water displaced by pipe, per unit length, lb/ft
α = coefficient of thermal expansion, 1/°F
σ_{sw} = circumferential compressive stress in the sidewalls, psi
ΔP = differential pressure due to negative internal pressure, psi
ΔT_{eq} = equivalent temperature rise, deg.F
ε_{soil} = maximum soil strain due to seismic wave passage
Ω = ring deflection
Ω_{max} = maximum allowable change in diameter as a per cent of the original diameter, commonly called the change in ring diameter, Table 3031-1
$\rho_{saturated}$ = density of saturated soil, lb/ft^3
ρ_{dry} = density of dry soil, lb/ft^3
ν = Poisson ratio (0.35 for short duration loads (5 min. or less) to 0.45 for long duration loads(greater than 5 min.))

-3012 Design Life

(a) The Design Specification shall specify the design life of the system, not to exceed 50 years.

(b) The duration of load shall be specified for each load case, and the HDPE pipe physical and mechanical properties shall be based on the duration of load.

-3016 Design and Service Loading

Design loads shall be as defined in ASME Section III, ND-3112.1 through ND-3112.3, except the design factor shall be 0.56 or lower. Miner's Rule in accordance with ISO 13760 shall be used to account for operation for 30 days at post-accident conditions and normal operating conditions for the balance of the 40 year design life. Loads applied to buried HDPE pipe shall be defined in the Design Specification, and shall include, as a minimum, the following:

(a) Maximum and minimum internal design gage pressure P_D, for pressure design in accordance with paragraphs -3021 and -3022.

(b) Maximum and minimum temperature T, for the selection of allowable stress (Tables 3021-1 and 3035-3) and design for temperature effects in accordance paragraph –3040. The maximum Service Level A temperature shall be the Design Temperature, T_D .

(c) The stress limits for the loads resulting from the maximum flow velocity, v, shall be as provided in paragraph -3021.2

(d) Vertical soil pressure P_E, including saturated soil, surcharge, buoyancy and flotation, for the designs in accordance with paragraph 3030.

(e) Vertical pressure due to weight of soil, P_E, and surcharge loads P_L for the design in accordance with paragraph 3030

(f) Permanent ground movement, soil settlement, for design as non-repeated anchor movements in accordance with paragraph -3030.

(g) Seismic wave passage and, seismic soil movement and building anchor motions, for seismic design in accordance with paragraph -3050.

-3021 Pressure Design of Pipe

-3021.1 Minimum Required Wall Thickness. The minimum required wall thickness of straight sections of pipe for pressure design shall be determined by

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

t_{design} = minimum required wall thickness, in
t_{min} = pressure design thickness, in
c = the sum of mechanical allowances and erosion allowance, in

$$t_{min} = \frac{P_D D}{(2S + P_D)}$$

t_{min} = pressure design thickness, in
P_D = Piping system internal Design Pressure (gage) at the specified Design Temperature T_D, both being specified in the Piping Design Specification. This pressure does not include the consideration of pressure spikes due to transients, psi
D = pipe outside diameter at the pipe section where the evaluation is conducted, in
S = allowable stress, psi, per Table 3021-1

Table 3021-1 Allowable Design Stress, S, for PE4710 (Dow DGDA-2490/2492)*(psi)

Service	Load Duration					
Temperature	2 Years			50 Years**		
°F	0.50 DF	0.56 DF	0.63 DF	0.50 DF	0.56 DF	0.63 DF
73	Not Applicable			800	889	1000
86	Not Applicable			738	826	929
95	Not Applicable			695	778	875
104	Not Applicable			653	732	823
113	Not Applicable			613	687	773
122	Not Applicable			574	643	724
131	Not Applicable			537	601	676
140	Not Applicable			500	560	630
176	340	382	430	Not Applicable		

* Values not applicable to all materials.
** For service temperature 140 °F (60°C), use 50-year allowable design stress for service life 50-years.

-3021.2 Allowable Service Level Spikes due to Transients Pressures. The sum of the maximum anticipated operating pressure plus the maximum anticipated Level B pressure spikes due to transients shall be no greater than 1.5 times the piping system Design Pressure (see paragraph -3021.1). The sum of the maximum anticipated operating pressure plus the maximum anticipated Level C and D pressure spikes due to transients shall be no greater than 2 times the piping system Design Pressure (see paragraph -3021.1).

-3022 Pressure Design of Joints and Fittings

-3022.1 High density polyethylene pipe shall be joined using the butt fusion process. All connections to metallic piping shall be flanged joints.

-3022.2 Sustained pressure and pressure rating of high density polyethylene pipe fittings shall comply with the specifications listed in Supplement 2. The pressure rating of fittings shall be equal to or greater than the attached straight pipe.

-3022.3 Flanged connections shall include a metallic back-up ring and shall provide a leak tight joint up to and including the piping hydrostatic test pressure. In addition, the maximum surge pressure per –3021.2 shall not cause permanent deformation of the pipe.

-3022.4 Mitered elbows shall comply with the requirements of ASME Section III, ND-3644. In place of ND-3644 (e) butt fusion joints shall be used in accordance with this document. In addition, the mitered elbow segments shall be a minimum of one dimension ratio (DR) lower than that of the attached straight pipe. Heavier wall segments with larger outside diameter (i.e. "inverted" elbows) will be used for elbow fabrication to minimize flow restriction. 90 degree, 45 degree and 22-1/2 degree elbows are permitted. Elbows less than 90 degrees may have fewer than three miter joints.

-3030 Soil and Surcharge Loads

-3031 Ring Deflection. The soil and surcharge loads on a buried HDPE pipe shall not cause the pipe diameter to deflect (ring deflection, Ω) beyond a limit Ω_{max} where

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

where

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

K = bedding factor = 0.1
L = deflection lag factor, 1.25 to 1.50, or 1.0 if using the soil prism pressure
P_E = vertical soil pressure due to earth loads, lb/ft^2
P_L = vertical soil pressure due to surcharge loads, lb/ft^2
E_{pipe} = apparent modulus of elasticity of pipe at design life, psi
DR = dimension ratio of pipe
D = pipe outside diameter, in
t = nominal pipe wall thickness at the pipe section where the evaluation is conducted, in
F_S = soil support factor, Table 3031-2
E' = modulus of soil reaction, psi
E'_N = modulus of soil reaction of native soil around trench, psi
B_d = trench width, ft
$\rho_{saturated}$ = density of saturated soil, lb/ft^3
ρ_{dry} = density of dry soil, lb/ft^3
H = height of ground cover, ft
H_W = height of water table above pipe, ft

Table 3031-1 Maximum Allowable Ring Deflection HDPE

DR	Ω_{max} (%)
13.5	6.0
11	5.0
9	4.0
7.3	3.0

Table 3031-2 Soil Support Factor F_S

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

Table 3031-3 Modulus of Elasticity of HDPE Pipe (ksi)

Load	Temperature (°F)				
Duration	≤73 °F	100 °F	120 °F	140 °F	175 °F
< 10 h	110	100	65	50	na
10 h	58	47	31	24	na
100 h	51	42	27	21	na
1000 h	44	36	23	18	na
1 y	38	31	20	16	na
10 y	32	26	17	13	na
50 y	28	23	15	12	12

-3032 Compression of Sidewalls. The circumferential compressive stress in the sidewalls σ_{sw} due to soil and surcharge loads shall not exceed

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

σ_{sw} = circumferential compressive stress in the sidewalls of pipe and miters, psi
P_E = vertical soil pressure due to earth loads, lb/ft^2
P_L = vertical soil pressure due to surcharge loads, lb/ft^2
DR = dimension ratio of pipe
S = allowable stress, psi, Table 3021-1

-3033 External Pressure.

-3033.1 Buckling Due to External Pressure. External pressure from ground water, earth loads, and surcharge loads on a buried HDPE pipe shall not cause the pipe to buckle.

$$[\ P_{hydro} = (P_E + P_L + P_{gw})\ ] / 144 \le 2.8\ [R \times B' \times E' \times E_{pipe} / 12\ (DR - 1)^3]^{1/2}$$

P_E = vertical soil pressure due to earth loads, lb/ft^2
P_L = vertical soil pressure due to surcharge loads, lb/ft^2
P_{gw} = pressure due to ground water, lb/ft^2
R = buoyancy reduction factor
E_{pipe} = modulus of elasticity of pipe, psi
E' = soil modulus, psi
DR = dimension ratio of pipe
B' = burial factor

and the buoyancy and burial factors are

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

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

H_{gw} = height of ground water above pipe, ft
H = depth of cover, ft

Table 3033.2-1 Ovality Correction Factor

Per Cent-Ovality	1%	2%	3%	5%	6%
Ovality Correction Factor	0.91	0.84	0.76	0.64	0.59

-3034 Flotation. Buried HDPE pipe shall have sufficient cover or be anchored to the ground to prevent flotation by groundwater. The upward resultant force due to buoyancy on a buried pipe in saturated soil is

$$W_W < W_P + P_E \times D/12$$

W_w = weight of water displaced by pipe, per unit length, lb/ft
W_P = weight of empty pipe per unit length, lb/ft
P_E = vertical soil pressure due to earth loads, lb/ft^2
D = pipe outside diameter, in

-3035 Longitudinal Stress Design

-3035.1 Longitudinal Applied Mechanical Loads, Longitudinal stresses due to axial forces and bending moments resulting from applied mechanical loads shall not exceed k x S where

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

B_1 = stress index, Table 3035-1
B_2 = stress index, Table 3035-1
P_a = Design or Service Level A, B, C, or D pressure, psi
D = outside pipe diameter at the pipe section where the evaluation is conducted, in
t = nominal pipe wall thickness at the pipe section where the evaluation is conducted, in
F_a = axial force due to the specified Design, Level A, B, C, or D applied mechanical loads, lb
A = cross section area of pipe wall at the pipe section where the force is calculated, in^2
M = resultant bending moment due to the specified Design, Level A, B, C, or D applied mechanical loads, in-lb
Z = section modulus of pipe cross section at the pipe section where the moment is calculated, in^3
k = factor from Table 3035-2
S = allowable stress, psi, Table 3021-1

Table 3035-1 Stress Indices

	DR 7	DR 9	DR 11	DR 13.5
B_1 Straight and Butt Fused Joint	0.5	0.5	0.5	0.5
B_2 Straight and Butt Fused Joint	1.0	1.0	1.0	1.0
B_1 Miter (a)	0.69	0.69	0.69	0.69
B_2 Miter (a)	1.38	1.64	1.91	2.21

(a) Mitered elbows shall not exceed 22.5 deg. per segment

Table 3035-2 Design and Service Level Longitudinal Stress Factors

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

-3035.2 Short Duration Longitudinal Applied Mechanical Loads. Alternatively, for the assessment of short duration loads (less than five minutes), the allowable stress S may be replaced by 40% of the tensile strength at material yield. The method for determination of the tensile strength at material yield are given in ASTM D 638 Standard Test Method for Tensile Properties of Plastics. For cell classification 445474C, short duration allowable stress values have been determined and are provided in Table 3035-3.

Table 3035-3 Short-Duration Allowable Stress Values

Temp (°F)	≤70	100	120	140	175
S (psi)	1200	940	770	630	400

-3040 Temperature Design

-3041 Minimum Temperature. The high density polyethylene material shall not be used at a temperature below the manufacturer limit, but in no case shall the temperature be less than minus 50°F.

-3042 Design for Expansion and Contraction

-3042.1 Fully Constrained Thermal Contraction. The tensile stress resulting from the assumption of fully constrained thermal contraction of the buried pipe when $T_{water} < T_{ground}$, increased by the tensile stress due to axial contraction from Poisson effect, shall not exceed the allowable stress S

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

S = allowable stress, psi
α = coefficient of thermal expansion, 1/°F
$\Delta T = T_{water} - T_{ground} < 0$
ν = Poisson ratio (0.35 for short duration loads to 0.45 for long duration loads)
E_{pipe} = modulus of elasticity of pipe, psi, Table 3031-3
P = internal design gage pressure, psi, including pressure spikes due to transients from anticipated waterhammer events
D = pipe outside diameter, in
t = nominal wall thickness, in

3042.2 Fully Constrained Thermal Expansion. The tensile stress resulting from the assumption of fully constrained thermal expansion of the buried pipe when $T_{water} > T_{ground}$, shall not exceed the allowable stress S

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

S = allowable stress, psi
α = coefficient of thermal expansion, 1/°F
$\Delta T = T_{water} - T_{ground} > 0$
E_{pipe} = modulus of elasticity of pipe, psi, Table 3031-3

-3042.3 Alternative Thermal Expansion or Contraction Evaluation. As an alternative to -3042.1 and –3042.2, the soil stiffness may be accounted for to calculate pipe expansion and contraction stresses. The stresses shall satisfy the following equation using the same differential temperatures as used in the fully constrained evaluations

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

i = stress intensification factor, Table 3042.2-1
F_{aC} = axial force range due thermal expansion or contraction and/or the restraint of free end displacement, lb
A = cross-section area of pipe at the pipe section where the force is calculated, in^2
M_C = resultant moment range due thermal expansion or contraction and/or the restraint of free end displacement, in-lb
Z = section modulus of pipe cross section at the pipe section where the moment is calculated, in^3

Table 3042.2-1 Stress Intensification Factor i

Fitting or Joint	i
Straight Pipe	1.0
Butt Fusion	1.0
Mitered Elbows	2.0

-3043 Non-Repeated Anchor Movements

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

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

i = stress intensification factor, Table 3042.2-1
F_{aD} = axial force due to the non repeated anchor motion, lb
A = cross-section area of pipe at the pipe section where the force is calculated, in^2
M_D = resultant moment due to the non repeated anchor motion, in-lb
Z = section modulus of pipe cross section at the pipe section where the moment is calculated, in^3
S = allowable stress, psi, Table 3021-1

-3050 Seismic Design
-3051 Seismic Induced Stresses

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

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

i = stress intensification factor, Table 3042.2-1

F_{aE} = axial force range due to the combined effects of seismic wave passage, seismic soil movement, and building seismic anchor motion effects, lb
A = cross-section area of pipe at the pipe section where the force is calculated, in^2
M_E = resultant moment range due to the combined effects of seismic wave passage, seismic soil movement, and building seismic anchor motion effects, in-lb
Z = section modulus of pipe cross section at the pipe section where the moment is calculated, in^3
S = allowable stress, psi, Table 3021-1

Seismic wave passage, seismic soil movement, and building seismic anchor motions shall be combined by square root sum of the squares or by algebraic sum.

Supplement 3 provides a non-mandatory method for the analysis of seismic wave passage, seismic soil movement, and building seismic anchor motion effects,

-3060 Design for Future Internal Access

Removable spools will be installed that would provide future access to the ID surfaces in each replacement line should suitable remote examination equipment be developed.

-4000 FABRICATION AND INSTALLATION

-4100 GENERAL REQUIREMENTS

-4110 Scope

This Article provides the requirements for the installation of PE piping and fittings. Methods of installation shall be by thermal fusion and flanged fittings. Use of threaded or adhesive joints with HDPE material is not permitted. All metallic interface components will be installed following the requirements of ASME Section III, Subsection ND.

-4120 Examinations

Examination activities that are not referenced for examination by specific Code paragraphs, and are performed solely to verify compliance with requirements of -4000, may be performed by the persons who perform or supervise the work. These visual examinations are not required to be performed by personnel and procedures qualified to -5100 and -5500, respectively, unless so specified.

-4130 REPAIR OF MATERIAL

HDPE material originally accepted on delivery in which defects exceeding the limits of -2300 are known or discovered during the process of fabrication or installation is unacceptable. The HDPE material may be used provided the defective area can be physically removed from the material or repaired in accordance with -2300.

-4200 CUTTING, FORMING, AND BENDING

-4210 Cutting

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

-4220 Forming and Bending Processes

The HDPE material shall not be cold or hot formed or bent. A pipe bending radius greater than or equal to 30 times the pipe outside diameter is acceptable for piping with a DR 9 through 13.5 and is considered to be straight pipe.

-4300 FUSING QUALIFICATIONS

-4310 General Requirements

(a) Fusing procedure and machine operator performance qualification shall comply with the requirements of Supplement 9.

(b) The Thermal Fusion Butt Joint is the only thermal fusion joint allowed, see Figure -4310-1.

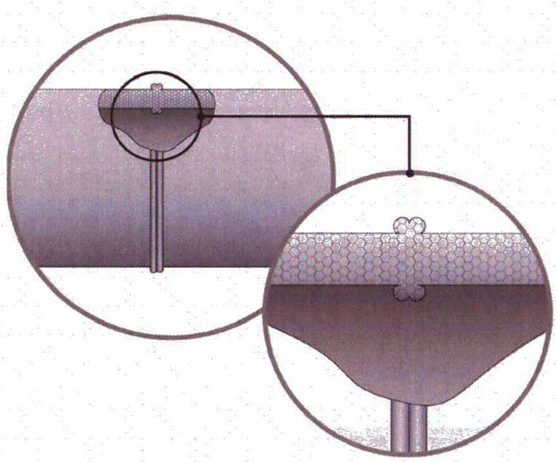


FIGURE -4310-1 Thermal Fusion Butt Joint

-4320 Qualifications

-4321 Required Qualifications

AmerenUE shall be responsible for all fusing performed for this project and shall establish the procedures, and conduct the tests required by Supplement 9 to qualify fusion machine operators who apply these procedures.

-4322 Maintenance and Certification of Records

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

-4323 Fusing Prior to Qualification

Fusing Procedure Specification (FPS) shall be qualified as required by Supplement 9 prior to their use. Only fusing operators who are qualified in accordance with -4320 and Supplement 9 shall be used.

-4324 Transferring Qualifications

The FPS qualifications and performance qualification tests for fusion machine operators shall not be transferred to another organization.

-4330 Requirements for Fusing Procedure Qualification Tests

-4331Conformance to Supplement 9 Requirements

All fusing procedure qualification tests shall be in accordance with the requirements of Supplement 9 as supplemented or modified by the requirements of this document.

-4332 Preparations of Test Coupons and Specimens

Removal of test coupons from the fusion test coupons and the dimensions of specimens made from them shall conform to the requirements of Supplement 9.

-4340 Performance Demonstration

-4341 AmerenUE will produce six (6) fusion joint test coupons of 36NPS DR 9.5 and six (6) fusion joint test specimens of 4NPS DR 9 material on each model of fusion machine carriage expected to be used in production for the respective size of piping as a performance demonstration. Three (3) of these fusions on each machine will target minimum temperature and interfacial pressure using maximum heater removal times, and three (3) will target maximum temperature and interfacial pressure using minimal heater removal times – to the extent feasible considering production limits, machine capabilities and the limits of the AmerenUE Fusion Procedure Specification.

-4342 A minimum of four (4) specimens will be cut from each fusion joint coupon approximately 90 degrees apart and tensile-tested to verify that the fusion joint is stronger than the pipe. Testing will be performed by commercial plastics industry suppliers without a 10 CFR 50 Appendix B quality program, but all testing will be overseen by AmerenUE representatives, and the test records will be retained in permanent Callaway records.

-4343 High speed impact tensile testing for the 4NPS specimens will be performed in accordance with QF-131. This testing will also be performed for the 36NPS specimens if determined feasible and conclusive considering the need – due to tensile machine capability - to test segmented specimens; otherwise, tensile testing for the 36 NPS specimens will be performed with full-section specimens consistent with ASTM Specification D638, "Standard Test Method for tensile Properties of Plastic."

-4400 RULES GOVERNING MAKING FUSED JOINTS

-4410 General requirements

-4411 Identification, Storage, and Handling of HDPE Materials

AmerenUE is responsible for control of the HDPE materials that are used in the fabrication and installation of components (-4120). Suitable identification, storage, and handling of HDPE material shall be maintained.

-4412 Cleanliness and Protection of Surfaces to Be Fused

The surfaces of the heater used for fusing shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during fusing operations. Fusing shall not be performed on wet surfaces. Fusing will not be performed below 50 deg F. Any fusing performed below ambient temperature of 50°F will require an environmental enclosure to be placed over the work area to control temperature.

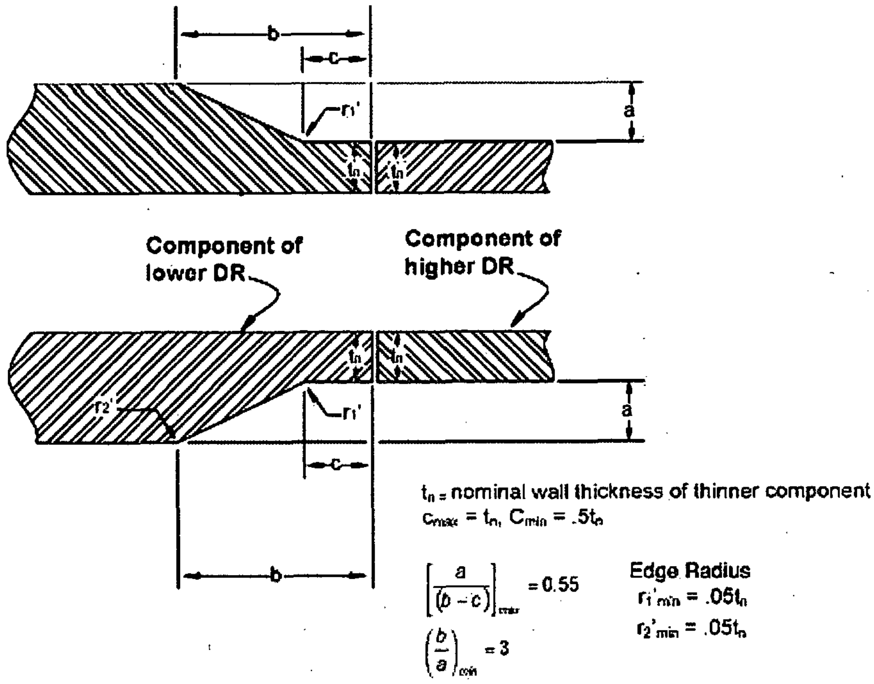
-4420 Rules For Making Fused Joints

-4421 Fused Joint Fit-up Requirements

(a) Components of different outside diameters shall not be fused together.

(b) The alignment of components for open butt fusion joints will be held in position by the fusing machine, allowable surface mismatch shall be less than 10% of the minimum wall thickness of the components being fused, and the remaining joint thickness shall not be less than the required as-fabricated minimum wall thickness per ASTM F714 – unless evaluated and determined to be acceptable considering the remaining wall thickness

c) To fuse components with differing DR's, the component with the smaller DR shall be countered-bored and tapered to meet the wall thickness of the component with the larger DR and shall comply with Figure –4421.3-1



$$\left[\frac{a}{(b-c)}\right]_{max} = 0.55$$

$$\left(\frac{b}{a}\right)_{min} = 3$$

Transition Counter-bore

FIGURE 4421.3-1

-4422 Identification of Joints by Fusing Operator

Each fusing operator shall apply the identification mark assigned to him adjacent to all permanent fused joints or series of joints on which he fuses. The marking shall be 1 ft (.3 m) or less from the fusion bead and shall be done with permanent metallic paint marker or stenciling marker.

-4423 Repairs

Repair of a fused joint is not allowed. All unacceptable joints shall be cut out and replaced.

-4430 Fusing Data Acquisition Recorder

The fusion machine shall have an automatic acquisition data recorder attached to it. The recorder shall record essential variables of the fusion process.

(a) Failure to run the recorder during the fusion process shall be cause to fail the fusion joint.

(b) The butt fusion joint record should be compared to the FPS to ensure that the proper butt fusion parameters and procedures were followed. If any parameter is out of the approved range, the fused joint shall be cut out and remade using the correct FPS.

-4500 ASSEMBLY AND ERECTION

-4510 General

Any distortion of piping to bring it into alignment for joint assembly which introduces a permanent strain in the piping or associated piping components is prohibited.

-4520 Flanged Joints using HDPE material

(a) Flanged connections are only permitted for the joining of high density polyethylene pipe to metallic pipe or piping components. The flange connection shall be constructed using a high density polyethylene flange adapter having a DR ratio equal to or less than that of the attached HDPE pipe and shall be joined by fusion to the attached high density polyethylene piping.

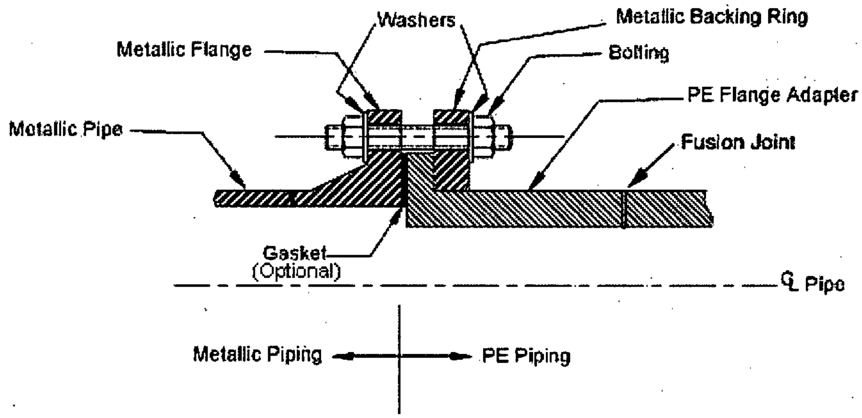
(b) The high density polyethylene flange adapter shall be connected to the metal flange using a metallic backing ring, The backing ring shall have a pressure rating equal to or greater than the metal flange.

(c) Following acceptable visual examination, the external fusion beads may be removed in order to accommodate installation of the metallic backing ring.

(d) Before bolting up, flange faces shall be aligned to the design plane within 1/16 in./ft measured across any diameter; flange bolt holes shall be aligned within 1/8 in. maximum offset. Damage to a gasket, if used, or seating surface on the HDPE flange which would prevent proper sealing shall be replaced per –2320(c).

(e) The flange shall be joined using bolts of a size and strength that conforms to the requirements of ASME B 16.5 or B16.47 as applicable. Bolts or studs should extend completely through their nuts. Any which fail to do so are considered acceptably engaged if the lack of complete engagement is not more than one thread. Flat washers shall be used under bolt heads and nuts

(f) In assembling flanged joints, the gasket, or high density polyethylene flange face if a gasket is not used, shall be uniformly compressed to the proper design loading. Special care shall be used in assembling flanged joints in which the flanges have widely differing mechanical properties. The required HDPE flange joint seating stress and bolt torque will be determined in accordance with the guidance provided in PPI document Technical Note TN-38, "Bolt Torque for Polyethylene Flanged Joints." If used, gasket material shall be selected to be consistent and compatible with the service requirements of the piping system. No more than one gasket shall be used between contact faces in assembling a flanged joint. See Figure -4520-1 for a typical flange configuration



Transition Flange Arrangement

FIGURE -4520-1

-4530 Pipe Supports

All installed HDPE pipe supports shall meet the requirements of Subsection NF and the following:

(a) Piping shall be supported, guided, and anchored in such a manner as to prevent damage to the piping. Point loads and narrow areas of contact between piping and supports shall be avoided. Suitable padding shall be placed between piping and supports where damage to piping may occur.

(b) Valves and equipment which would transmit excessive loads to the piping shall be independently supported to prevent such loads.

-5000 EXAMINATION
-5100 GENERAL REQUIREMENTS

(a) Visual examinations shall be conducted in accordance with the examination method of Section V, Article 9.

(b) All personnel qualified to perform Visual Examinations on HDPE pipe (VT-1 examinations), excluding the hydrostatic pressure test (VT-2 examinations), shall receive the same training as required for the fusion machine operator in Supplement 9. This training shall include the use of a fusion machine to make a fused joint; however this joint is not required to be tested for qualification. This training shall be documented on a training record.

(c) In addition, personnel performing VT-1 inspections shall undergo evaluation involving examination of physical samples of visually acceptable and unacceptable HDPE pipe fusion joints. A minimum of five flaw samples will be used for the visual examination procedure demonstration, and five for the personnel demonstration using the visual examination procedure

-5110 Procedures

Examination Procedures. All examinations shall be executed in accordance with detailed written procedures which have been proven by actual demonstration, to the satisfaction of the Authorized Nuclear Inspector. Written procedures, records of demonstration of procedure capability, and personnel qualification shall be made available to the Authorized Nuclear Inspector on request.

-5120 Time of Examination of Completed Fused Joints

Visual examination of all fused joints shall be conducted;

(a) upon the completion of cooling period;
(b) after the review required by paragraph –4430 has been reviewed and accepted; and
(c) shall be completed before piping becomes inaccessible for inspection.

-5200 REQUIRED EXAMINATIONS

-5210 Visual Examinations are required on the following material and components.

(a) During receipt inspection of the external surface for indentations.

(b) Fusion joints after the fusion process includes, review and verification of fusion data for the joint, and external surfaces. Joints that are not examined in accordance with -5220 shall be visually inspected on the interior of the joint, including the interior beads of mitered joints.

(c) All pipe fusion joints during the hydrostatic test.

-5220 Time-of-Flight Diffraction (TOFD) Examination

To provide added assurance of joint integrity, AmerenUE will perform ultrasonic Time-of-Flight Diffraction (TOFD) examination of all completed fusion joints, with the exception of portions of joints where the geometry prohibits effective examination (i.e. intrados and extrados areas of mitered fitting joints).

(a) This is a non-standard non-Code examination, and the contractor providing the service will not have a 10CFR50 Appendix B program. AmerenUE personnel will oversee the examinations.

(b) A demonstration will be performed to verify that the Time-of-Flight Diffraction (TOFD) procedure utilized will apply available technology for this technique. The demonstration will utilize specimen(s) containing ten flaws of varying shapes, dimensions and relative locations, simulating flaws expected to occur in unacceptable joints.

(c) Personnel performing TOFD examinations will be qualified in accordance with SNT-TC-1A or equivalent.

(d) Acceptance criteria will be evaluated and refined by AmerenUE, and will be based on industry standards (e.g. B31 piping codes). The current acceptance criteria require that any unbonded area in the joint, found as a result of the TOFD, is cause for rejection.

(e) All TOFD joint examination records shall be retained as permanent records.

-5300 ACCEPTANCE STANDARDS

-5310 General Requirements

Unacceptable joints shall be removed. Repair of unacceptable joints is not permitted.

-5320 Visual Examination Acceptance Criteria of external surfaces

-5321 Thermal fusion butt joints shall meet the following:

(a) Joints shall exhibit proper fusion bead configuration, see Supplement 5.

(b) There shall be no evidence of cracks or incomplete fusion.

Except for mitered joints, joints shall not be visually angled or off-set. The ovality offset shall be less than 10% of the minimum wall thickness of the fused components provided the remaining joint thickness is not be less than the required as-fabricated minimum wall thickness per ASTM F714 - unless evaluated and determined to be acceptable considering the remaining wall thickness.

(c) The cleavage between fusion beads shall not extend to or below the outside diameter pipe surface (see Figure –5321-1).

(d) For mitered joints, the beads may flare out instead of roll back to the pipe surface, and/or may exhibit multiple beads or heavy beads with no cleavage. In either case, there must be evidence of melt flow around the complete interior and exterior circumference of the joint. Refer to Supplement 5.

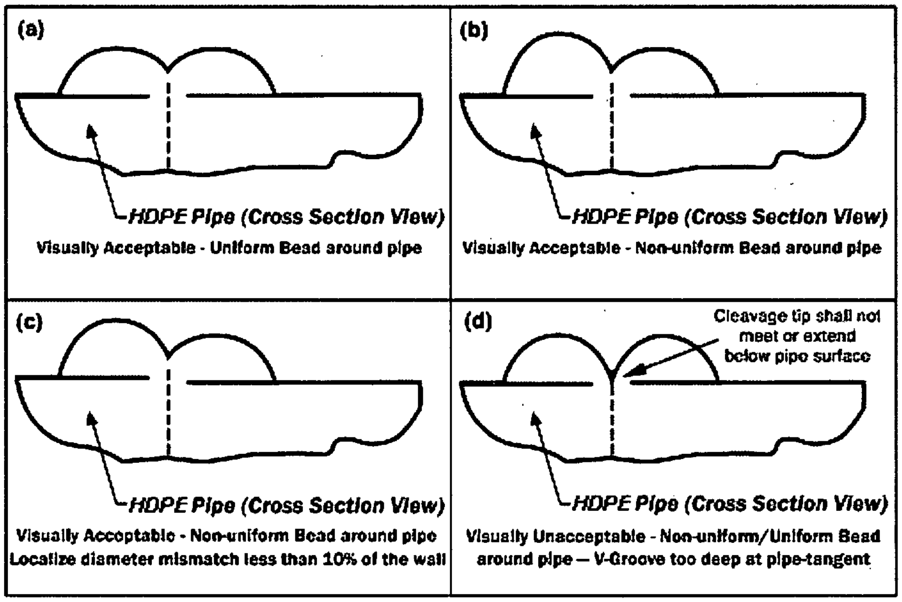


FIGURE -5321-1

(e) Review the data acquisition record for the joint and compare it to the Fusion Procedure Specification (FPS) to ensure the proper parameters and procedures were followed in making the fused joint, see paragraph –5330.

-5330 Process Verification

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

-5500 QUALIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

-5510 General Requirements

Code required nondestructive examinations shall utilize personnel qualified in accordance with ND-5520, as applicable. All Code required nondestructive examinations shall be performed by and the results evaluated by qualified nondestructive examination personnel.

-5520 Personnel Qualification Requirements

(a) Personnel performing visual examinations required by –5200 (a) and (b) shall be qualified and certified as a VT-1 in accordance with IWA-2000 and shall receive the required training and evaluation in paragraph –5100(b) & (c).

(b) Personnel performing visual examinations required by -5200(c) shall be qualified and certified as a VT-2 in accordance with IWA-2000 and receive four hours of training in PE piping and joining practices. This training shall be documented on a training record.

-6000 TESTING
-6100 GENERAL REQUIREMENTS

(a) Prior to initial operation, the installed system shall be hydrostatically tested in the presence of the Authorized Nuclear Inspector.

(b) All joints, including fused joints shall be left exposed for examination during the test. For long sections of piping the hydrostatic testing may be accomplished by testing in small sub-sections of the longer section. Upon a satisfactory test of each small section the piping may be buried. This process shall be documented in the AmerenUE Quality Assurance Program or Repair/Replacement Program and found acceptable to the Authorized Nuclear Inspector.

(c) The pressure in the test section shall be gradually (minimum rate of 5 psig/min not to exceed a maximum rate of 20 psig/min) increased to the specified test pressure and held for 4 hours. Make up water may be added to maintain test pressure during this time to allow for initial expansion. Following the 4 hour initial pressurization period, the test pressure shall be reduced by 10 psig and the system monitored for anther 1 hour. Make up water may no longer be added to maintain pressure. Each joint shall be examined. If no visual leakage is observed and the pressure remains within 5% of the test pressure for the 1 hour, the pipe section under test is considered acceptable.

(d) The temperature of the piping under test will be maintained within the temperature limits of the system design.

(e) The total test time including initial pressurization, initial expansion, and time at test pressure, must not exceed 8 hours. If the pressure test is not completed the test section shall be de-pressurized. The test section shall not be re-pressurized for at least 8 hours.

(f) A pneumatic test is not permitted.

-6200 Hydrostatic Test Requirements

(a) Instrumentation for the hydrostatic test shall be in accordance with IWA-5260.

(b) The minimum test pressure shall be 1.5 times the Design Pressure of the HDPE piping system plus 10 psi.

(c) Personnel qualified in accordance –5520(b) shall conduct the examination.

-8000 NAMEPLATES, STAMPING AND REPORTS
-8100 GENERAL REQUIREMENTS
-8110 Scope

The requirements for nameplates, stamping and reports shall be in accordance with AmerenUE's ASME Section XI Repair/Replacement Program with the following exception:

(a) Other than thermal indentation line printing during manufacture, no indentation stamping is allowed on the high density polyethylene pipe surface, all marking shall be performed with a metallic paint marker or stenciling marker.

(b) Form NM(PE)-2 (Supplement 2) shall be used for batch produced products produced by fusion (i.e. shop fabricated fittings). Multiple fittings may be included on one Data Report Form.

SUPPLEMENT 1

GLOSSARY

1. Butt Fusion Cycle - Pressure/Time diagram for a defined fusion temperature, representing the butt fusion operation.

2. Certified Certificate of Analysis for Batch (CCAB) – a document attesting that material is in accordance with specified requirements, including batch analysis of all chemical analysis, test, and examinations.

3. control specimen – The specimen from the base material tested to determine the tensile strength for the purpose of determining an acceptable tensile strength.

4. Cool time under Pressure - In the fusion process, the theoretical fusion pressure plus drag pressure is applied between the pipe ends. This pressure must be maintained until the fusion joint is cool to the touch.

5. coupon – a fusion assembly for procedure or performance qualification testing. The coupon may be any product from sheet plate, pipe, or tube material.

6. Data Acquisition Record - A detailed record of the times and pressures used in the fusion process along with the heater surface temperature , employee information, fusion machine information, pipe information, date and time for a permanent record of each joint made.

7. Drag Pressure - The pressure required by the fusion machine to overcome the drag resistance and frictional resistance and keep the carriage moving at its slowest speed.

8. Drag Resistance - Frictional resistance due to the weight of the length of pipe fixed in the movable clamp at the point at which movement of the moveable clamp is initiated (peak drag) or the friction occurring during movement (dynamic drag)

9. Frictional Resistance in the Butt Fusion Machine - Force necessary to overcome friction in the whole mechanism of the butt fusion machine.

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

11. Fusion Operator Certificate - Approval certificate issued by the examiner/assessor stating the knowledge and the skill of the fusion operator to produce fusion joints following a given fusion procedure.

12. Fusion Procedure - A document providing in detail the required variables for the butt fusion process to assure repeatability in the butt fusion procedure (FPS).

13. Heater Bead-up Size - In the heating cycle, the pipe is brought against the heater and the force is dropped to the soak cycle. During this cycle, a bead of polyethylene is formed between the pipe end and the heater surface on both sides. When the bead-up size reaches the size established in the FPS, it is time to open the carriage and remove the heater.

14. Heater Surface Temperature - The temperature, in degrees F, of the surface of the coated heater is critical to the butt fusion process. It is usually expressed as a range (example: 400 - 450° F) and the common practice is to set the average surface temperature at the mid-range (example: 425° F).

15. hydrostatic design basis (HDB) – one of a series of established stress values for a compound.

16. 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 pipe will not occur. This stress is circumferential when internal hydrostatic water pressure is applied.

17. Interfacial Pressure - The amount of force in pounds (lbs) per square inch of pipe area required to calculate the fusion machine gauge pressure. The interfacial pressure is multiplied by the pipe area in square inches to determine the amount of fusion force (lbs) required to fuse the pipe. This force is divided by the total effective piston area of the hydraulic fusion machine to determine the theoretical gauge pressure to set on the fusion machine. The Drag pressure must be added to this pressure to determine the actual gauge pressure required for fusion. The interfacial pressure usually has a range (example: 60-90 psi) and the common practice is to use the mid-range (example: 75 psi) when making these calculations.

18. long-term hydrostatic pressure - strength (LTHS) – the estimated tensile stress in the wall of the pipe in the circumferential orientation that when applied continuously will cause failure of the pipe at 100,000 hours.

19. Modulus of Soil Reaction, E' - The soil reaction modulus is a proportionality constant that represents the embedment soil's resistance to ring deflection of pipe due to earth pressure. E' has been determined empirically from field deflection measurements by substituting site parameters (i.e. depth of cover, soil weight) into Spangler's evaluation and "back calculating" E'.

20. HDPE – (high density polyethylene) A polyolefin composed of polymers of ethylene. It is normally a translucent, tough, waxy solid which is unaffected by water and by a large range of chemicals. This is one of three general classifications based on material density; low-density, medium-density, and high-density.

21. product quality certification (PQC) – a document attesting that material is in accordance with specified requirements, including batch analysis of all chemical analysis, test, and examinations.

22. stiffness factor – the measurement of a pipe's ability to resist deflection as determined in accordance with ASTM D 2412.

23. test joint – work pieces joined by fusing to qualify fusing procedures, or fusing operators

24. thermoplastic resin - a resin material which does not react or polymerize and which flows with the application of heat and solidifies when cooled. A material which can be reformed.

SUPPLEMENT 2

ASTM PE MATERIAL STANDARDS

The following PE materials standards are acceptable for use,

1. D-3035, Standard Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter

2. D-3261, Standard Specification for Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing

3. D-3350, Standard Specification for Polyethylene Plastics Pipe and Fittings Materials

4. F-714, Standard Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter

5. F-1055, Standard Specification for Electro fusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Pipe and Tubing

6. F-2206, Standard Specification for Fabricated Fittings of Butt-Fused Polyethylene (PE) Plastic Pipe, Fittings, Sheet Stock, Plate Stock, or Block Stock

SUPPLEMENT 3

Non-Mandatory Method

The buried pipe may be qualified by analysis for the effects of seismic wave passage, following the method provided in this Appendix.

Step-1. The strains from seismic wave passage, and seismically-induced permanent or temporary movements if any, shall be obtained by a plant-specific geotechnical-civil investigation.

Step-2. The soil strains (Section 3051) shall be converted into an equivalent temperature rise of the buried pipe, as follows

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

ΔT_{eq} = equivalent temperature rise, deg.F
ε_{soil} = maximum soil strain due to seismic wave passage
α = coefficient of thermal expansion of the pipe, 1/°F

Step-3. The pipe-soil system shall be modeled as a piping system constrained by soil springs.

(a) The pipe model shall consider two cases: short-term modulus (< 10 hours, Table 3031-3) for wave passage and long-term modulus for permanent soil movement (permanent seismic anchor motion).

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

For guidance on modeling soil-pipe interaction, refer to ASCE, Guidelines for the Seismic Design of Oil and Gas Pipeline Systems, 1984, ASCE 4 Seismic Analysis of Safety-Related Nuclear Structures and Commentary, or American Lifelines Alliance, Guidelines for the Design of Buried Steel Pipes, July 2001, with February 2005 addendum

Step-4. The equivalent change of temperature ΔT_{eq} shall be applied to the pipe-soil model, to obtain forces and moments throughout the system.

Step-5. The anticipated building seismic anchor movements, if any, shall be applied to the pipe-soil model to obtain forces and moments throughout the system.

Step-6. The anticipated seismic movements, if any, shall be applied to the pipe-soil model to obtain forces and moments throughout the system.

Step-7. The results of Steps 4, 5, and 6 shall be combined by SRSS or algebraic sum, at each point along the piping system to obtain resultant forces and moments.

Step-8. The resultant forces and moments shall be evaluated as follows:

(a) The axial stresses in pipe, fittings and fused joints shall comply with the requirements of 3051.

(b) Alternatively, the seismic induced strain shall be determined as follows:

$$(\varepsilon_a)_{Earthquake} = [\ |\sigma_E| + |\nu (PD / 2t)|\ ] / E$$

Where:

$(\varepsilon_a)_{Earthquake}$ = Strain in the pipe from earthquake wave computer analysis

This strain, $(\varepsilon_a)_{Earthquake}$ shall be limited to the values listed in Table A-1, where k is defined in Table 3035-2

Table A-1 Seismic Strain Limits

DR	Allowable Strain
DR ≤ 13.5	0.025 x k
13.5 < DR ≤ 21	0.020 x k
DR > 21	0.017 x k

SUPPLEMENT 4

FORMS

1. Form NM(PE) -2 Data Report for Non-Metallic Batch Produced Products

2. Form QF-200 Fusion Procedure Specification (FPS)

3. Form QF-300 Fusion Machine Operator Qualification (FPQ)

FORM NM(PE)-2 DATA REPORT FOR NON METALLIC BATCH PRODUCED PRODUCTS REQUIRING FUSING

As required by the Provisions of the AmerenUE 10CFR50.55a Request Number I3R-10

1. Manufactured by ____
   (Name and address of Manufacturer of Non Metallic products)
2. Manufactured for ____
   (Name and address of purchaser)

3. a) Identification- Certificate Holder's Serial No. ______________________________
   (Lot No., Batch No., etc.) (Print string)

   ____
   (Nat'l Board No.) (yr. mfg.)

   b) Owner ____

4. Manufactured according to Mat'l Spec. ____________ Purchase Order No.____________________
   (ASTM)
5. Remarks:

____
(Brief Description of F____________

CERTIFICATE OF COMPLIANCE

We certify the statements made in this report are correct and the products defined in this report conform to the requirements of the ASME Material specification listed above on line 4. The Certified Material Batch Reports provided for the material covered by this report.

Date __________________, 20__ Signed _______________________By ________________________

ASME Certificate of Authorization (NA if Owner) No. ____________to use the _________ Symbol expires ___________
(Date)

CERTIFICATE OF INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of ___________________________and employed by

____

of ________________________________have inspected the products described in this Partial Data Report product in accordance with the ASME Section III, Division 1, AmerenUE 10CFR50.55a Request Number I3R-10.

By signing this certificate, neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the product described in this Partial Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date __________ 20__

______________________________Commissions______________________________________
(Inspector's Signature) National Board, State, Province and No.

*Supplemental sheets in form of lists, sketches or drawings may be used provided (1½ize is 8 1/2 in. x 11 in. (2) information on items 1-4 on this Data Report is included on each sheet, and (3) each sheet is numbered and number of sheets is recorded at the top of this form.

FORM QF-200

ASME CC N-755	FUSION PROCEDURE SPECIFICATION

title:

Prepared by: Date: Approved by: Date:

MATERIAL:

FUSION MACHINE INFO:

DATA ACQ. MFGR:

DATA ACQ. ATTACHED:

FUSION INTERFACIAL PRESSURE:

HEATER SURFACE TEMPERATURE:

FUSION DRAG PRESSURE:

FUSION PRESSURE:

BEAD - UP SIZE

HEATER REMOVAL TIME:

COOL TIME & FUSION PRESSURE:

TECHNIQUE:

FORM QF-300

FUSION MACHINE OPERATOR
PERFORMANCE QUALIFICATION (FPQ)
TEST FORM

,

Operator's Name______________________ **Payroll No.**_________ **Stamp I.D.**_______

Lab Test No.____________ **Test: Qualification** ________ **Requalification** ________

Fusion Machine Manufacturer ____

Fusion Machine Pipe Size Range ______________________________________

Test Position ____

Material Specification __________ **to** __________

Fusion Specification Procedure _______________________

Pipe Size _____________ **Pipe DR** _______________

NDE Requirements: Visual __________________ **Visual Results** __________________

Free Bend Test _______________ Bend Tests Results _______________

Data Acquisition Record Review Results _________________________________

Test Conducted By ____

We certify that the statements in this record are correct and that the fused joints are prepared, fused and tested in accordance with the requirements of Supplement 9, of AmerenUE 10CFR50.55a Request Number I3R-10.

Date ______________________ **Signed By** ____

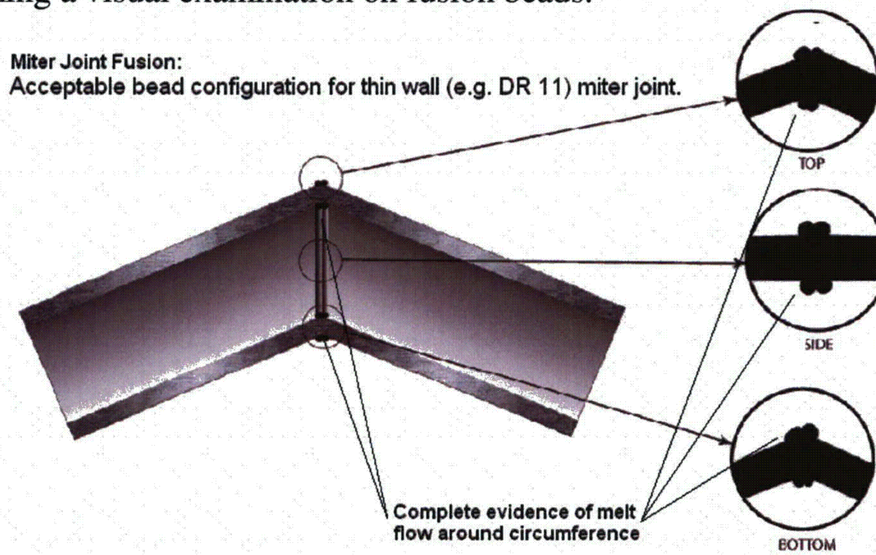
Title

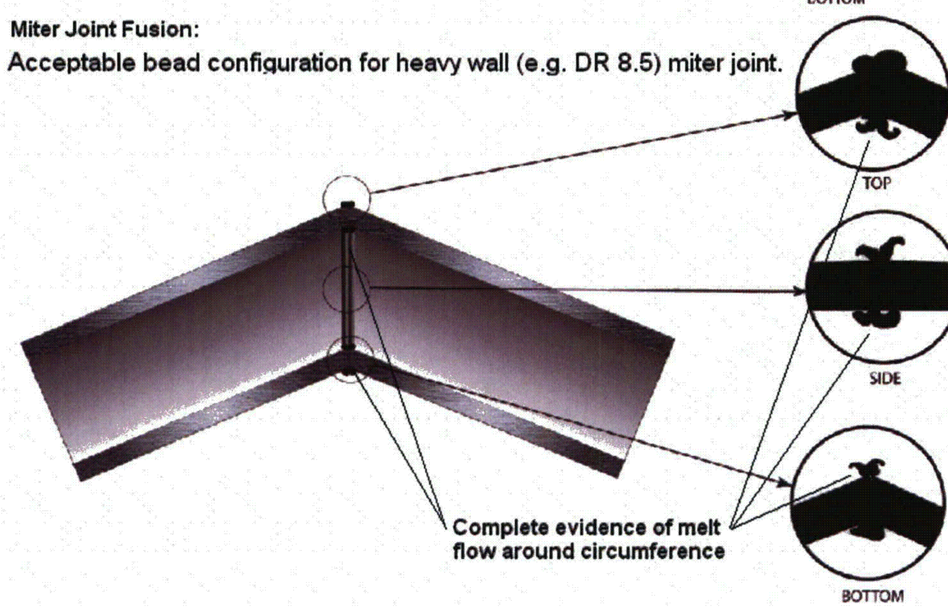
____

SUPPLEMENT 5

FUSION BEAD CONFIGURATION

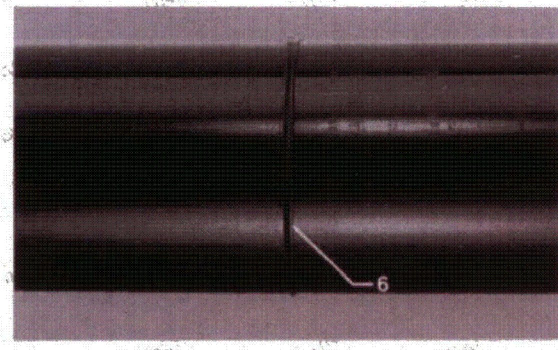
The following page contain pictures of critical attributes of the completed thermal fusion butt joints. These pictures may be used by personnel performing a visual examination on fusion beads.





Butt Fusion of Pipe

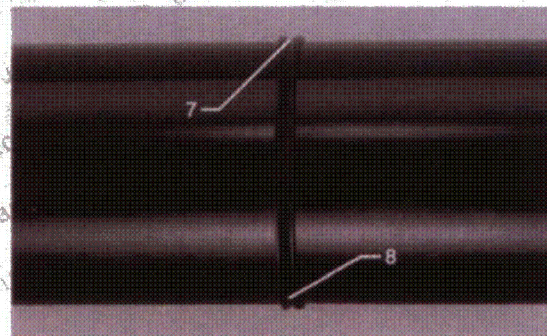
Unacceptable Appearance – Insufficient Melt



6. Melt Bead Too Small For 2-Inch And Larger Mains

Butt Fusion of Pipe

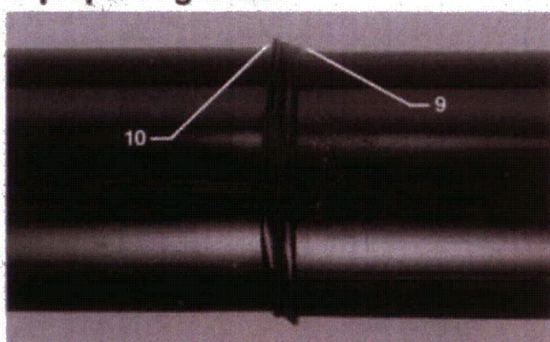
Unacceptable Appearance – Inadequate Roll Back



7. Insufficient Fusion Pressure – "V" Shaped Melt Appearance
8. Inadequate Roll Back of Bead

Butt Fusion of Pipe

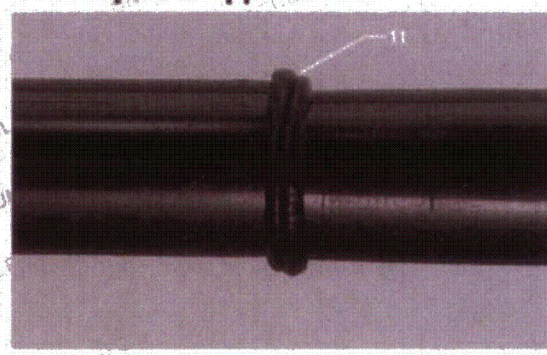
Unacceptable Appearance – Improper Alignment



9. "High-Low" Condition 10. Inadequate Roll Back Of Bead Due To Improper Alignment

Butt Fusion of Tubing

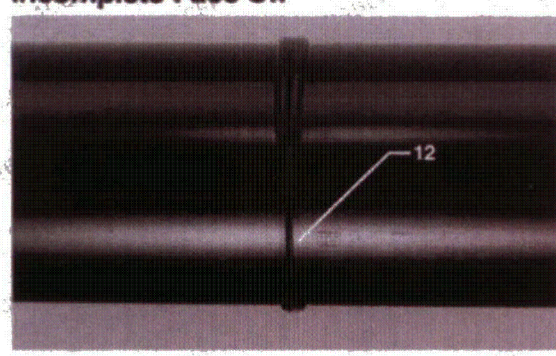
Unacceptable Appearance



11. Excessive Melt, Improper Alignment And/Or Excessive Pressure

Butt Fusion of Pipe

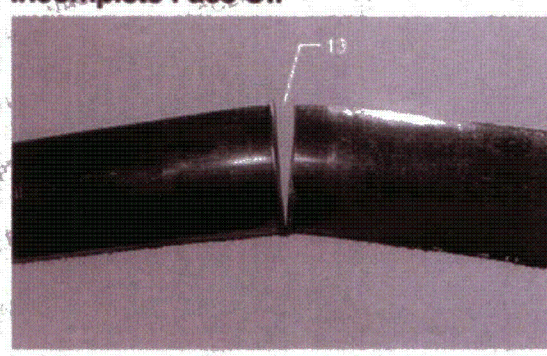
Unacceptable Appearance – Incomplete Face Off



12. No Melt Bead Caused By Incomplete Face Off

Butt Fusion of Pipe

Unacceptable Appearance – Incomplete Face Off



13. Unbonded Area In Joint Of Cut Strap

SUPPLEMENT 9

HIGH DENSITY POLYETHYLENE PIPE FUSING

1. Article I -- Fusion General Requirements

1. Article II -- Fusion Procedure Qualifications

2. Article III -- Fusion Performance Qualification

3. Appendixes

Non-mandatory Appendix A -- Fusion Machine Operator Qualification Training

ARTICLE I
FUSION GENERAL REQUIREMENTS

QF-100 GENERAL

This Supplement relates to the qualification of fusion machine operators and the procedures that they employ in fusing high density polyethylene (HDPE) piping. Due to the major differences between metallic welding and plastic fusing, the Fusion Procedure Specification (FPS) and the Procedure Qualification Record (PQR) have been combined for this supplement.

QF-101 Scope

The requirements in this supplement apply to the preparation of the Fusion Procedure Specification (FPS), and the qualification of fusion machine operators for thermal butt fusion joining.

QF-102 Terms and Definitions

Some of the more common terms relating to fusion are defined in Supplement 1, and ASTM F412 Standard Terminology Relating to Plastic Piping Systems,

QF-103 Responsibility

QF-103.1 Fusion. AmerenUE is responsible for all fusing done for the project and shall conduct the tests required in this Supplement to qualify procedures (Article II), and the performance of fusion machine operators who use these procedures (Article III).

QF-103.2 Records. Records of the results obtained in the fusing procedure and fusion machine operator performance qualifications shall be maintained. These records shall be certified by AmerenUE and shall be accessible to the Authorized Nuclear Inspector.

QF-104 Documents

QF-104.1 A FPS is a written document that provides direction to the fusion machine operator for making fused joints in accordance with the requirements of this Supplement.

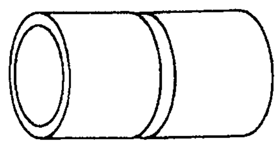
(a) The FPS specifies the conditions under which the fusing must be performed. These conditions include the HDPE materials that are permitted. Such conditions are referred to in this Supplement as fusing "essential variables." The FPS shall address these essential variables.

(b) When required, qualification of a FPS is intended to determine that the fused joint proposed for construction is capable of providing the required properties for its intended application. FPS qualification establishes the properties of the fused joint, not the skill of the fusion machine operator.

QF-104.2 In performance qualification, the basic criterion established for fusion machine operator qualification is to determine the operator's ability to operate the fusing equipment to produce a sound fused joint.

QF-105 Joint Orientation

The orientation of all fused butt joints produced for tests or production shall be made with the horizontal axis position illustrated in Figure QF-105.



Horizontal Axis Position

Figure QF - 105

QF-106 Training

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

(1) The theoretical test shall cover as a minimum; safety, fundamentals of the fusing process, and recognition of typical joint imperfections.

(2) Performance Qualification test using an approved FPS.

(b) Appendix A to this supplement provides guidance for a training program.

QF-120 EXAMINATIONS

QF-121 Visual Examination. All fused joints shall receive a visual examination. The examination shall include all accessible surfaces of the fused joint and shall meet the following criteria;

(a) Joints shall exhibit proper fusion bead configuration, see Supplement 5.

(b) There shall be no evidence of cracks or incomplete fusion.

(c) Except for mitered joints, joints shall not be visually mitered (angled, off-set). The ovality offset shall be less than 10% of the minimum wall thickness of the fused components.

(d) The cleavage between fusion beads shall not extend to or below the outside diameter pipe surface (see Figure QF–121-1).

(e) For mitered joints, the beads may flare out instead of roll back to the pipe surface, and/or may exhibit multiple beads or heavy beads with no cleavage. In either case, there must be evidence of melt flow around the complete interior and exterior circumference of the joint. Refer to Supplement 5.

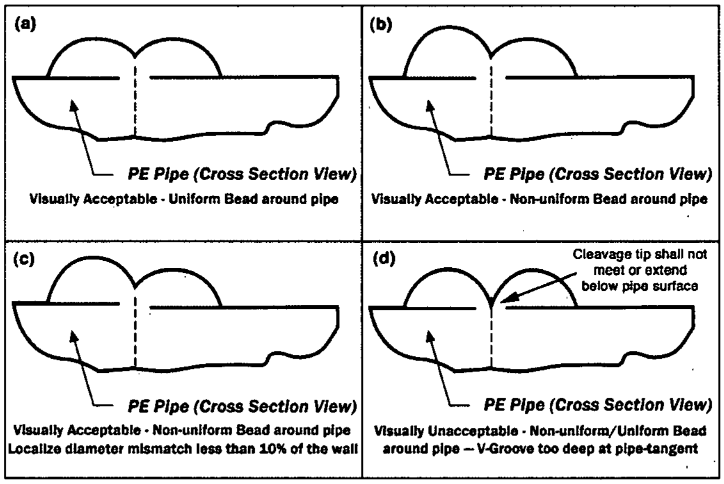


FIGURE QF-121-1

(f) Review the data acquisition record for the joint and compare it to the Fusion Procedure Specification (FPS) to ensure the proper parameters and procedures were followed in making the fused joint, see paragraph QF-122.

QF-122 Data Acquisition Record Evaluation.

QF-122.1 Data Acquisition Device

(a) The data recording device must be capable of recording the following butt fusion essential variables on each joint:

1) Heater Surface temperature
2) Interfacial Pressure
3) Gauge Pressure during the heat cycle
4) Gauge Pressure during the fusion/cool cycle
5) Time during the heat cycle
6) Time during the fusion/cool cycle
7) Heater removal time

(b) All job information related to the joints such as job number, joint number, employee number, time, date, fusion machine identification, pipe manufacturer and pipe material

(c) The data recording device must be capable of storing at least (1) day of butt fusion joint information and capable of downloading this information as a permanent record.

QF-122.2 Data Acquisition Log Evaluation

The butt fusion joint record should be compared to the FPS to ensure that the proper butt fusion parameters and procedures were followed. If they were not, the joint should be cut and re-fused using the correct parameters and procedures per the FPS.

(a) Verify that all job related data was entered in the record.

(b) Verify that the recorded "Fuse" interfacial pressure was within the range of qualification.

(c) Verify that the heater surface temperature recorded was within the range of qualification.

(d) Verify that the Drag Pressure was recorded.

(e) The examiner must calculate the fusion pressure for the fusion machine and add the drag pressure to confirm the machine's hydraulic fusion gauge pressure. This fusion gauge pressure must be shown in the recorded pressure/time diagram at the initial heater contact and during the fusion/cool cycle.

(f) Verify that the fusion gauge pressure dropped quickly to a value less than or equal to the drag pressure at the beginning of the heat soak cycle.

(g) At the end of the heat soak cycle, review that the machine was opened, the heater removed and the pipe ends brought together at the fusion gauge pressure as quickly as possible (not to exceed allowance in procedure).

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

QF-130 Tests

QF-131 High Speed Tensile Impact Test.

QF-131.1 Significance and Use

This test method is designed to impart tensile impact energy to a butt fused plastic pipe specimen. The failure mode (brittle or ductile) are used as criteria in the evaluation of the butt fusion joint.

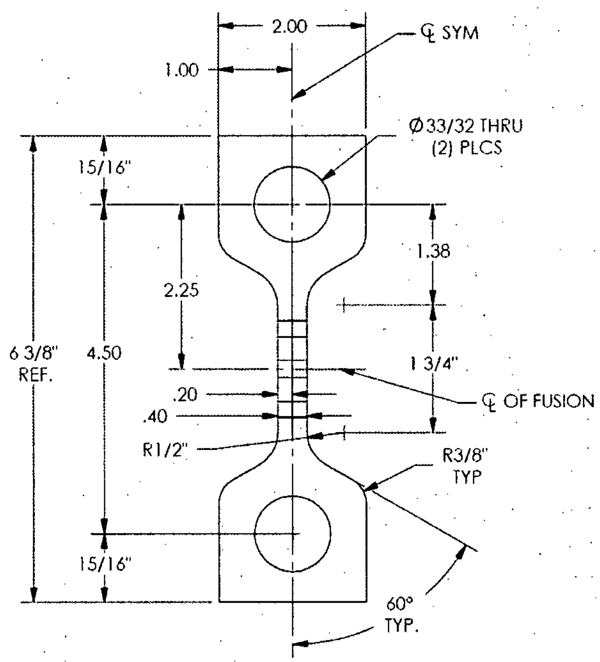
QF-131.2 Test Specimens

(a) The test specimen shall conform to the dimensions shown in Figure QF-131.2. Test specimens of butt fused pipe shall have the bead remain on the outside and inside. Test specimens of butt fused pipe shall use the full wall thickness.

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

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

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



NOTES:

1. ALL MACHINED SURFACES 125 RMS OR BETTER

Tensile Full Thickness Impact Test Coupon Configuration

Figure QF-131.2

QF-131.3 Number of Test Specimens

Test at least four specimens from butt fused pipe sections 90° apart for pipe sizes 4" and larger. Test two specimens from butt fused pipe sections 180° apart for pipe sizes 2" to 4".

QF-131.4 Speed of Testing The speed of testing shall be in accordance with Table QF-131.4

Wall Thickness	Testing Speed
≤1.25 in. (32 mm)	6 in. /s (152 mm/s)
>1.25 in. (32 mm)	4 in. /s (102 mm/s)

Testing Speed Tolerance: +5 in./s to -1 in./s (+12.7 mm/s to -25.4 mm/s)

TABLE QF-131.4

QF-131.5 Conditioning

(a) Conditioning—Condition the test specimens at 73.4 ± 4°F [23 ± 2°C] for not less than 1 hour prior to test.

(b) Test Conditions—Conduct the tests at 73.4 ± 4°F [23 ± 2°C] unless otherwise specified by contract or the relevant ASTM material specification.

QF-131.6 Test Procedure

(a) Set up the machine and set the speed of testing to the proper rate as required in QF-131.4

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

(c) Determine the mode of failure and note in the report.

QF-131.7 Acceptance Criteria

Failure mode shall be ductile. Reference Figure QF-130.7.

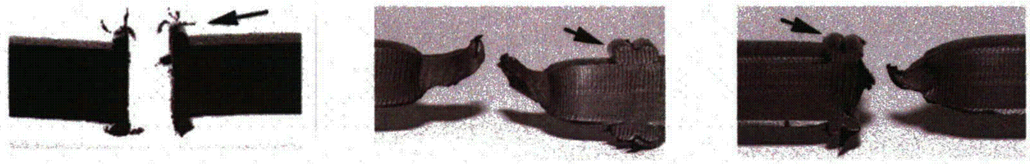


Figure A
Brittle Failure

Figure B
Ductile Failure
Outside Fusion Interface

Figure C
Ductile Failure
Adjacent to Fusion Interface

NOTE: ◄—— Denotes Fusion Bead

FIGURE QF-130.7 Tensile Test Sample Evaluation Sample

QF-132 Elevated Temperature Sustained Pressure Tests.

QF-132.1 Specimens

Butt fuse (2) pieces of 8" IPS DR 11 PE 3408/PE 4710 pipe x 40" long using the FPS outlined in this Supplement and perform the elevated temperature sustained pressure tests specified in ASTM D-3055-03a.

QF-133 FREE BEND TESTS

QF-133.1 Specimens

Two bend specimens as shown in Figure 133.1 shall be removed from the joint approximately 180° apart. For qualification coupons greater than 1" thick, alternative means of bend testing may be used provided similar cross-sectional stress is obtained at the joint.

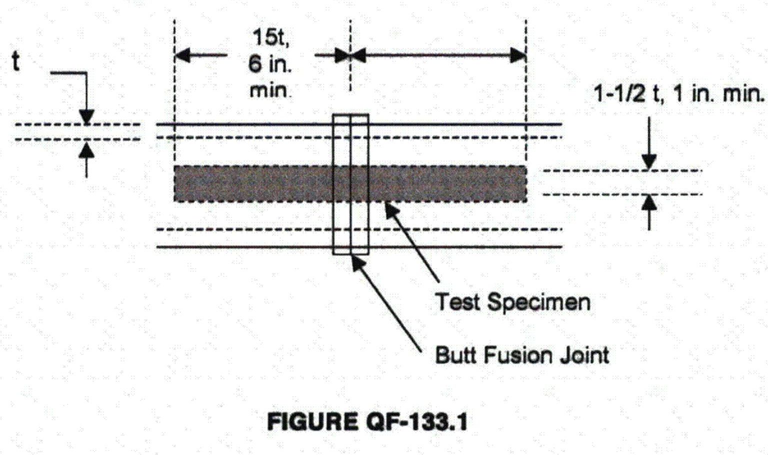


FIGURE QF-133.1

QF-133.2 Testing Procedure

One test specimen shall be bent so that the inside surface of the joint is in tension and the other shall be bent so that the outside surface of the joint is in tension. The ends of each specimen shall be brought together until the ends of the specimens touch.

QF-133.3 Acceptance Criteria

The specimens shall not crack or fracture.

ARTICLE II

FUSION PROCEDURE QUALIFICATIONS

QF-200 GENERAL

QF-201 Written Fusion Procedure Specifications shall be prepared as follows:

(a) Fusion Procedure Specification (FPS). A FPS is a written qualified fusing procedure prepared to provide direction for making production fused. The FPS shall be used to provide direction to the fusion machine.

(b) Contents of the FPS. The completed FPS shall describe all of the essential variables for each fusion process used in the FPS. These essential variables are listed and defined in QF-220. Any other information may be included in the FPS that may be helpful in making a fused joint.

(c) Changes in essential variables require requalification of the FPS

(d) Format of the FPS. The information required to be in the FPS may be in any format, written or tabular, as long as every essential variables outlined in QF-220 is included or referenced. Form QF-200 has been provided as a guide for the FPS. This Form includes the required data for the fusing, it is only a guide and is located in Supplement 4.

(e) Availability of the FPS. A FPS used for production fusing shall be available for reference and review by the Authorized Nuclear Inspector at the fabrication or installation site.

QF-210 Responsibility

(a) The parameters applicable to fusing that are performed in construction of fusion joints shall be listed in a document known as a Fusion Procedure Specification (FPS).

(b) The FPS shall be qualified by the fusing of test coupons, testing of specimens cut from the test coupons, and recording fusing data and test results in the FPS. The fusion machine operators used to produce the fused joints to be tested for qualification of procedures shall be under the full supervision and control of

AmerenUE during the production of these test fused joints. The fused joints to be tested for qualification of procedures shall be fused either by direct employees or by individuals engaged by contract for their services as fusion machine operators under the full supervision and control of AmerenUE. It is not permissible to have the supervision and control of fusing of the test fused joints performed by another organization. It is permissible, however to subcontract any or all of the work of preparation of test material for fusing and subsequent work on preparation of test specimens from the completed fused joint, performance of nondestructive examination, and mechanical tests, provided AmerenUE accepts the responsibility for any such work.

(c) AmerenUE has responsible operational control of the production of all fusion joints to be made for this project.

(d) AmerenUE shall certify each Fusion Procedure Specification.

QF-220 FUSION PROCEDURE SPECIFICATION (FPS)

QF-221 STANDARD FUSION PROCEDURE SPECIFICATION

(a) The Standard Fusion Procedure Specification is based on standard industry practice and testing as reported in the Plastics Pipe Institute (PPI), report TR-33/2001,

(a) (b) When the FPS is limited to the following parameters, qualification testing is not required. If there are to be deviation from the conditions listed below, procedure qualification testing in paragraph QF-223 shall be performed.

(1) The pipe material is PE3408 or PE4710

(2) Position is limited to horizontal, ±45°.

(3) The pipe ends shall be faced to establish clean, parallel mating surfaces that for non-mitered joints are perpendicular to the pipe centerline on each pipe end. When the ends are brought together, there shall be no visible gap.

(4) The external surfaces of the pipe are aligned to within 10% of the pipe wall thickness.

(5) The drag pressure shall be measured and recorded. The fusion pressure shall be calculated so that an interfacial pressure of 60 to 90 psi is applied to the pipe ends.

(6) The heater plate surface temperature shall be 400 to 450°F measured at 4 locations approximately 90° apart on both sides of the heater plate.

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

(8) The ends shall be held in place until the following bead size is formed between the heater faces and the pipe ends, shown in Table QF-221(a)-1.

Approximate Melt	
Pipe Size (Dia) inches	**Bead Size inches**
≤ 1 1/4	1/32 to 1/16
> 1 1/4 to < 3	1/16
≥ 3 to ≤ 8	1/8 to 3/16
> 8 to ≤ 12	3/16 to 1/4
> 12 to ≤ 24	1/4 to 7/16
> 24 to ≤ 36	7/16 to 9/16
> 36 to ≤ 54	9/16 minimum

TABLE QF-221(a)-1

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

(10) The maximum time from removal of the heating plate until the pipe ends are pushed together shall not exceed the time given in Table QF-221(a)-2.

Pipe Wall Thickness (inches)	Max. Heater Plate Removal Time
.20 to .36	8 sec.
> .36 to .55	10 sec.
> .55 to 1.18	15 sec.
>1.18 to 2.0	25 sec.
> 2.0 to 4.0	45 sec.
> 4.0 to 6.0	60 sec.
Shop Application	
>3.0 to 4.0	60 sec.
>4.0 to 6.0	75 sec.

TABLE QF-221(a)-2

(11) The pressure is maintained until the joint has cooled to the touch, after which the pipe may be removed from the joining machine. Handling of the pipe shall be minimized for an additional 30 minutes.

QF-222 Essential variables for Fusion Procedure Specifications (FPS).

Any change in the essential variables listed below and QF –221, requires requalification of the FPS per QF –223.

(a) Essential Variables

(1) The pipe material,

(2) Heater surface temperature range,

(3) Butt fusion interfacial pressure range,

(4) Deleted (redundant to 3)

(5) Heater bead up size,

(6) Heater removal time,

(7) Cool-down time under fusion pressure

QF-223 Testing Procedure to Qualify the FPS

(a) Use 8" IPS HDPE DR11 pipe sizes in qualification test joints.

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

(1) High heater surface temperature and high interfacial pressure, (5) joints
(2) High heater surface temperature and low interfacial pressure, (5) joints
(3) Low heater surface temperature and high interfacial pressure, (5) joints
(4) Low heater surface temperature and low interfacial pressure, (5) joints

(c) Evaluate (3) joints of each combination using the High Speed Tensile Impact Tests per QF-131. All joints must fail in a ductile mode.

(d) Evaluate (2) joints of each combination using the Sustained Pressure Testing per QF-132. All joints must pass this test.

QF-230 Mechanical Tests.
QF-231 General Requirements

(a) The type and number of test specimens that shall be tested to qualify a butt FPS are given in QF-223, and shall be removed in a manner similar to that shown in QF-130. If any test specimen required by QF-223 fails to meet the applicable acceptance criteria, the test coupon shall be considered as failed.

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

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

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

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

QF-232 Preparation of Test Coupon

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

ARTICLE III

FUSION PERFORMANCE QUALIFICATION

QF-300 GENERAL

QF-300.1 This Article lists the essential variables that apply to fusion machine operator performance qualifications.

The fusion machine operator qualification is limited by the essential variables.

QF-300.2

(a) The basic premises of responsibility in regard to fusion are contained within QF-103 and QF-301.2. AmerenUE shall be responsible for conducting tests to qualify the performance of fusion machine operators in accordance with qualified Fusion Procedure Specifications, which are employed in the construction of fused joints built in accordance with this Supplement. This responsibility cannot be delegated to another organization.

(b) The fusion machine operators used to produce such fused joints shall be tested under the full supervision and control of AmerenUE during the production of these test fused joints. It is not permissible to have the fusing performed by another organization. It is permissible, however, to subcontract any or all of the work of preparation of test materials for fusing and subsequent work on the preparation of test specimens from the completed fused joints, performance of nondestructive examination and mechanical tests, provided AmerenUE accepts full responsibility for any such work.

(c) AmerenUE is the organization which has responsible operational control of the production of the fused joints to be made in accordance with this Supplement.

QF-301 Tests

QF-301.1 Intent of Tests. The performance qualification tests are intended to determine the ability of fusion machine operators to make sound fused joints.

QF-301.2 Qualification Tests. AmerenUE shall qualify each fusion machine operator for the fusing process to be used in production. The performance qualification test shall be fused in accordance with a qualified Fusion Procedure Specifications (FPS). Changes beyond which requalification is required are given in QF-322. Allowable visual and mechanical examination requirements are described in QF-303. Retests and renewal of qualification are given in QF-320.

The fusion machine operator who prepares the FPS qualification test coupons meeting the requirements of QF-200 is also qualified within the limits of the performance qualifications, listed in QF-303 for fusion machine operators.

The performance test may be terminated at any stage of the testing procedure, whenever it becomes apparent to the supervisor conducting the tests that the fusion machine operator does not have the required skill to produce satisfactory results.

QF-301.3 Identification of Fusion machine operators. Each qualified fusion machine operator shall be assigned an identifying number, letter, or symbol which shall be used to identify the work of that fusion machine operator.

QF-301.4 Record of Tests. The record of Fusion machine operator Performance Qualification (FPQ) tests shall include the essential variables, the type of test and test results, and the ranges qualified in accordance with Form QF-300 for each fusion machine operator.

QF-302 Type of Test Required

QF-302.1 Mechanical Tests. All mechanical tests shall meet the requirements prescribed in QF-133.

QF-302.2 Test Coupons in Pipe. For test coupons made on pipe in the horizontal axis position of Figure QF-105. The coupons shall be removed from the test piece in accordance with Figure QF-133.1.

QF-302.3 Visual Examination. For pipe coupons all surfaces shall be examined visually per QF-121 before cutting of bend specimens. Pipe coupons shall be visually examined per QF-121 over the entire circumference, inside and outside.

QF-303 Fusion machine operators

Each fusion machine operator who fuses under the rules of this Supplement shall have passed the mechanical and visual examinations prescribed in QF-302.1 and QF-302.3 respectively.

QF-303.1 Examination. Fused joints made in test coupons for performance qualification shall be examined by mechanical and visual examinations (QF-302.1, QF-302.3).

QF-310 QUALIFICATION TEST COUPONS

QF-310.1 Test Coupons. The test coupons shall be pipe. Qualifications for pipe are accomplished by fusing one pipe assembly in the horizontal axis position (figure QF-105). The minimum pipe size shall be IPS 6.

QF-320 RETESTS AND RENEWAL OF QUALIFICATION

QF-321 Retests

A fusion machine operator who fails one or more of the tests prescribed in QF-303, as applicable, may be retested under the following conditions.

QF-321.1 Immediate Retest Using Visual Examination. When the qualification coupon has failed the visual examination of QF-302.3, retesting shall be by visual examination before conducting the mechanical testing.

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

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

QF-321.2 Immediate Retest Using Mechanical Testing.

When the qualification coupon has failed the mechanical testing of QF-302.1, the retesting shall be mechanical testing.

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

QF-321.4 Further Training. When the fusion machine operator has had further training or practice, a new test shall be made.

QF-322 Expiration and Renewal of Qualification

QF-322.1 Expiration of Qualification. The performance qualification of a fusion machine operator shall be affected when one of the following conditions occurs:

(a) When he has not performed thermal butt fusion during a period of 6 months or more, his qualification shall expire.

(b) When there is a specific reason to question his ability to make fused joints that meet the specification, the qualifications that support the fusing he is doing shall be revoked.

QF-322.2 Renewal of Qualification

(a) Renewal of qualification expired under QF-322.1(a) may be made by fusing a single test coupon and by testing of that coupon as required by QF-301. A successful test renews the fusion machine operator previous qualifications for the process for which he was previously qualified.

(b) Fusion machine operators whose qualifications have been revoked under QF-322.1(b) above shall requalify. Qualification shall utilize a test coupon appropriate to the planned production work. The coupon shall be fused and tested as required by QF-301 and QF-302. Successful test restores the qualification.

QF-330 FUSION ESSENTIAL VARIABLES FOR FUSION MACHINE OPERATORS

QF-331 General

A fusion machine operator shall be requalified whenever a change is made in one or more of the essential variables listed.

(a) A change in pipe diameter from one range to another;
  (1) Less than IPS 8,
  (2) IPS 8 to IPS 24. and
  (3) IPS over 24

(b) A change in name of the manufacturer of equipment

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

QF-340 Testing

(a) Test joints shall be 6" IPS minimum. A data acquisition device shall be attached to the fusion machine and the data concerning the joint entered. The data acquisition device shall be used to record data required by QF-122.

(b) The supervisor conducting the test shall observe making of the butt fusion joint and note if the fusion procedure (FPS) was followed.

(c) The completed joint shall be visually examined and meet the acceptance criteria of QF-121.

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

(e) Bend test specimens shall be removed, tested and meet the acceptance criteria in accordance with QF-133.

Non-Mandatory
Appendix A
To
Supplement 9

Fusion Machine Operator Qualification Training

A-1000 SCOPE

(a) The major portion of the quality of HDPE piping systems is determined by the skills of the fusion machine operators. When installing polyethylene (PE) piping, the quality of the fusion joints is essential for the piping system.

(b) It is important that the fusion machine operators are trained and competent in the fusion technology employed in constructing HDPE piping systems. Continued competence of the fusion operator is covered by periodic re-training and re-assessment.

(c) This document gives guidance for the training, assessment and approval of fusion operators in order to establish and maintain competency in construction of high density polyethylene piping systems for pressure applications. The fusion joining technique covered by this Appendix is butt fusion. This article covers both the theoretical and practical knowledge necessary to ensure high quality fusion joints.

A-1100 REFERENCES

(a) Plastics Pipe Institute (PPI) Technical Report TR-33/2001 "Generic Butt Fusion Joining Procedure for Field Joining of Polyethylene Pipe

(b) American Society of Testing and Materials (ASTM) D 2657-03 "Standard Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings"

(c) ISO TR 19480/2005 "Thermoplastics pipes and fittings for the supply of gaseous fuels or water – Guidance for training and assessment of fusion operators"

A-2000 TRAINING

A-2100 Training Course

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

(b) The course will be delivered by a competent qualified trainer with a minimum of 3 years of experience in the butt fusion processes and who has mastered the techniques involved.

(c) The trainer should have a range of fusion machines representative of the equipment encountered on worksites for installing pipes, in order for the trainee fusion operator to become acquainted with the fusion equipment commonly used. The trainee fusion operator may be trained on one of these fusion machines or on a machine from his own company if accepted by the training center. The fusion equipment must comply with the fusion machine manufacturer's specifications and/or ISO 12176-1 "Plastics pipes and fittings — Equipment for fusion jointing polyethylene systems — Part 1: Butt fusion ".

A-2200 Operator Assessment

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

A-2300 Training Curriculum

(a) The training course should comprise of any combination of fusion packages based on the requirements of utility or pipeline operators. These packages may be given as individual modules or combined to suit requirements. The course shall include safety training related to the fusion process and equipment.

(b) All consumables and tools necessary for the training package should be available during the training session. The pipes and fittings to be used shall conform to the ASTM product forms permitted by this Supplement.

(c) The lessons should be designed so that the trainee fusion operator learns to master the fusion technique and attains a good working knowledge of the piping system materials and practical problems encountered when fusing pipe in the field. The fusion operator should receive a written manual covering all the elements dealt with in the training.

(d) The theoretical course should deal with general information in connection with raw materials, pipes and fittings, and also with theoretical knowledge about preparation, tools, and devices, joining components, different materials, different diameter ratios and correct and incorrect parameters. The safety course should include information concerning the fusion process, such as protective clothing, general safety, regulations for electrical equipment, handling heater plates, etc. Areas of study should include but not be limited to the following:

(1) Butt fusion joining

- Principles of fusion
- Straight/coiled pipes, service lines, main lines, etc.
- Components: pipes, flange adapters saddle fittings, other fittings
- Butt fusion equipment: manual, semi-automatic and automatic machines.
- Joint preparation: Cleaning, rounding, alignment, facing, etc
- Butt fusion cycle: pressure, time and temperature relationships, diagram.
- Failure modes: understanding and avoiding possible errors
- Test methods: visual examination, high speed tensile-impact test, bending test, hydrostatic test, data log recording / evaluation, etc.

(2) The trainee fusion operator should be familiar with the butt fusion joining technique and procedure (FPS) by making a sufficient number of butt fusion joints. In some cases, the fusion technique may vary slightly according to diameter, material or other factors. In such cases, the trainee fusion operator should also be made familiar with the various techniques.

(3) The trainee should start by making a butt joint between two pipes, and should then learn to make butt fusion joints with pipes and fittings such as tees, reducers, etc.

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

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

A-3000 ASSESSMENT AND TESTING

(a) Training program should end with a theoretical and practical examination (test piece).

(b) The content of the theoretical examination shall consist of not less than (20) multiple choice questions about the butt fusion process, fusion machine operation, pipe, quality examination, safety, etc. within a set period of time. A score of 80% or better is considered passing on this examination. Questions to be included but not limited to are:

How do you calculate the fusion machine gauge pressure?
What is the proper heater surface temperature range from the FPS?
What is the proper butt fusion interfacial pressure range from the FPS?
How do you calculate the drag pressure?
How do you know when to remove the heater in the heating cycle?
How long do you leave the pipe ends together under pressure in the cooling cycle?
What is the difference between IPS pipe and DIPS pipe?
How do I determine the hydraulic fusion machines total effective piston area?
How is the total effective piston area of the fusion machine used to determine the fusion machines gauge pressure for a specific pipe?
How do you adjust the machine to improve the alignment of the pipe after facing?
How much material should be removed from the pipe ends in the facing operation?
How do you determine if the fusion machine conforms to the equipment manufacturer's specifications?
How do you align the pipe in the butt fusion machine?
Can you butt fuse pipe in a ditch?
What is interfacial pressure?

(c) The practical examination will require the trainee fusion operator to make a fusion joint with a hydraulic butt fusion machine with a minimum pipe size of 6" IPS DR11. A data acquisition device must be attached to the fusion machine and the data concerning the joint entered. The data log device shall be used to record the joint made by the trainee. The assessor shall observe the butt fusion joint and note if the proper procedure (FPS) was followed. After the joint is complete, the data log record shall be reviewed by the assessor and compared to the FPS to ensure the proper procedures was followed. The assessor will then conduct a visual examination of the joint to make sure it satisfies the pipe manufacturers recommend visual guidance criteria per QF-121 of this Supplement.

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

(e) Trainee fusion operators who pass the theoretical and practical examination would receive a fusion operator certificate bearing the logo of the assessment center awarding the approval. The fusion operator certificate should state the technique or techniques and fusion machines for which the operator is qualified.

A-4000 REASSESSMENT

If the trainee fails one of the examinations, he should retake it after a period not shorter than one week. If the trainee fails the examination for the second time, the trainee should repeat the training course before taking the test again.

Enclosure 6

Justification for Increase in Callaway's HDPE Design Factor

Justification for Increase in Callaway's HDPE Design Factor

A Design Factor (DF) of 0.5 has historically been used in the determination of allowable stress for pipe design utilizing PE 3408 piping material. For the PE 4710 High Density Polyethylene (HDPE) piping material to be installed in Callaway's Essential Service Water (ESW) system, AmerenUE intends to use a Plastics Pipe Institute (PPI) DF of 0.56 (i.e. a safety factor of 1.8) to provide sufficient design margin.

The bases for increasing the DF from 0.5 to 0.56 in the replacement Callaway ESW HDPE piping are as follows:

1) The PPI DF is not determined using the same method as the ASME DF. The allowable stress determined using a PPI DF of 0.56 will actually result in a DF greater than 3.5 (the ASME DF for ASME Section III, Class 3 piping) using the ASME method.

2) PE 4710 material will be used in the replacement Callaway ESW HDPE piping rather than PE 3408. It has been accepted by PPI that PE 4710 has superior properties when compared to other PE materials and that it is therefore appropriate to use a higher PPI DF in the design of PE 4710 piping systems. Additionally, as discussed below, the primary failure mechanism for HDPE piping is slow crack growth. The PE 4710 material selected for use at Callaway significantly exceeds the requirements for slow crack growth resistance with a PENT (Pennsylvania Notch Test - ASTM F 1473) of greater than 10,000 hours as compared to the requirement to exceed 500 hours.

3) The replacement Callaway ESW HDPE piping and fittings are all being manufactured from the same PE 4710 material. The purpose of the design factor in the ASME Code is to account for the unknowns in the design and construction process. One such unknown is variation in materials. By manufacturing all of the HDPE piping and fitting from the same material and at the same facilities, the material variability is reduced.

These bases are discussed below in further detail.

Basis 1 – Comparison of PPI DF and ASME DF

The PPI DF is based on a ratio of the recommended allowable stress (Hydrostatic Design Stress or HDS) to the nominal long term stress rating (Hydrostatic Design Basis or HDB). The HDB for the Dow PE 4710 material selected for use in the Callaway ESW replacement piping is 1600 psi at 73°F. (Reference: Enclosure 1 of Reference 2, ULNRC-05490.) Values of the resulting Hydrostatic Design Stress (HDS) for the Dow PE 4710 material for various DF values are presented below.

Hydrostatic Design Basis (HDB) at 73°F (psi)	PPI Design Factor (-)	Hydrostatic Design Stress (HDS) at 73°F (psi)
1600	0.5	800
1600	0.56	896
1600	0.63	1000

The ASME DF is based on the tensile strength of the material. The following illustrates the ASME DF that would exist for the HDPE material using the ASME method for determining the DF.

The tensile strength of the Dow PE 4710 material is 3600 psi. (Reference: Enclosure 1 of Reference 2, ULNRC-05490, and Enclosure 3.)

A calculation for the ASME allowable stress using an ASME DF of 3.5 would be:

3600 psi / 3.5 = 1030 psi

However, if a Hydrostatic Design Stress (HDS) of 896 psi is used (based on the PPI DF of 0.56), the ASME DF would be:

3600 psi / 896 psi = 4.0

Basis 2 – Superior Properties of PE 4710 Material

Approximately four decades ago, PPI developed the standard 0.50 design factor for thermoplastic pressure water pipe service that is used throughout North America. This 0.50 DF is the inverse of a 2.00 safety factor. This factor was developed by determining safety factors for application components with regards to uncertainty in material, pipe manufacture, handling, installation, application operating characteristics, and unknown factors. The following is a breakdown of these factors:

1.00	Starting basis
0.25	Materials variability from lot to lot, and for variability in testing and test methods
0.05	Extrusion quality variation
0.10	Extension of the HDB from 11.4 years to 50 years
0.20	Pressure surge variations (based on PVC water hammer capacity at 2 fps water velocity)
0.20	Handling and installation
0.20	Unknown factors
2.00	TOTAL SAFETY FACTOR

Over the years, the plastic pipe industry has determined that the 0.50 DF has proved to be conservative for pressure-rated thermoplastic materials, i.e., PVC, CPVC, ABS, PP, and conventional PE (including PE 3408 material). However, as discussed below, PE 4710 materials demonstrate a higher level of performance without the risk of service life reduction. As a result, PPI recommends a higher design factor of 0.63 (or a safety factor of 1.6) for PE 4710 materials for water service based on a reduction or elimination of several of the individual factors as follows:

1.00	Starting basis
0.25	Materials variability from lot to lot, and for variability in testing and test methods
0.05	Extrusion quality variation
0.00	Extension of the HDB from 11.4 years to 50 years
0.00	Pressure surge variations (based on PVC water hammer capacity at 2 fps water velocity)
0.30	Handling and installation and Unknown factors
1.60	TOTAL SAFETY FACTOR

For the application at Callaway, a DF of 0.56 (or a safety factor of 1.8) will be used based on the exclusion of the 0.20 factor for pressure surge variations only. This factor is excluded since the 0.20 surge allowance is based on limiting PVC material to surge pressure from a 2 foot-per-second (fps) velocity change to prevent bursting. In contrast, and as noted in the PPI Handbook of PE pipe, PE 4710 material tolerates far higher surge pressures.

Excerpts below are taken from PPI TN-41, "High Performance PE Materials for Water Piping Applications," and provide additional justification on the use of the lower DF of 0.56 for the PE 4710 material.

Background

Polyethylene (PE) has been used for water piping applications both domestically and internationally since the 1960's. In 1988, high performance PE materials were introduced in Europe. Recognizing the advantages afforded by higher-performing PE materials, PPI and ASTM worked to characterize higher-performing PE materials that culminated in PE 4710 designations that are now manufactured in the U.S. by a number of resin companies. Pipe made from these PE 4710 materials have a unique combination of having the highest PE pressure rating (PR), outstanding resistance to slow crack growth (SCG), and increased resistance to rapid crack propagation (RCP). These are the three key engineering properties for evaluating a plastic piping material, and these high performance PE materials exhibit outstanding performance in all three areas.

Although these high performance PE materials may be relatively new in North America, they have over 20 years of very successful history worldwide for water piping applications.

The Plastics Pipe Institute (PPI) identified that the best way to take advantage of these high performance PE materials in North America was to incorporate them into the ASTM and AWWA standards by applying higher material specifications that result in an increased hydrostatic design stress compared to conventional PE materials. Changes to support a higher HDS for water piping have been accomplished through revising PPI TR-3 and existing ASTM PE resin and pipe standards. The higher HDS for pressure rating can be a deciding factor whether a water company uses PE pipe or metal pipe. The premise for this increased HDS is that higher performing PE materials must demonstrate superior performance characteristics such that PE pipe would provide a safer, cost effective alternative piping system.

III. ASTM Pressure Rating Method

The ASTM pressure rating method utilizes pipe samples tested at a constant temperature with the log stress vs. log time regression line extrapolated to 100,000 hours. This extrapolated value is the long-term hydrostatic strength (LTHS) of the material, and the categorized value of the LTHS is called the Hydrostatic Design Basis (HDB) in accordance with ASTM standard test method D 2837. This HDB is reduced to a maximum working stress by a design factor (DF) to establish the Hydrostatic Design Stress (HDS). The HDS is the product of the HDB and the design factor for water:

HDS = HDB x DF (for water)

HDB and HDS values for various thermoplastic materials used for piping applications are published in PPI TR-4 which is available on the PPI website www.plasticpipe.org. These PPI listings of HDB and HDS values are classified in accordance with the material's standard pipe material designation code. In this designation system, the plastic pipe material is identified by its standard abbreviated terminology in accordance with ASTM D 1600, "Standard Terminology Relating to Abbreviations, Acronyms, and Codes for Terms Relating to Plastics," followed by a four or five digit number. The first two or three digits, as the case may be, code the material's ASTM classification (short-term properties) in accordance with the appropriate ASTM standard specification for that material. The last two digits of this number represent the PPI recommended HDS for water at 73°F (23°C) divided by 100. Examples of pipe material designation codes for PE materials are as follows:

- PE 3408 is a polyethylene (the PE abbreviation is in accordance with ASTM D 1600) with a density cell class of 3 and a slow crack growth (SCG) cell class of 4 (in accordance with ASTM D 3350). It has an 800 psi maximum recommended HDS (based on a design factor of 0.5) for water at 73°F (23°C).

- PE 4710 is a polyethylene (the PE abbreviation is in accordance with ASTM D 1600) with a density cell class of 4 and a slow crack growth (SCG) cell class of 7 (in accordance with ASTM D 3350). It has a 1000-psi maximum recommended HDS (based on a design factor of 0.63) for water at 73°F (23°C).

IV. PPI Program

A coordinated industry effort was undertaken to revise PPI documents and ASTM/AWWA/CSA standards to recognize the improved performance properties of these high-performance PE materials. These newly defined performance properties enabled expanded classification of PE materials, and justified the use of a higher hydrostatic design stress for water piping applications. Several changes to PPI documents and ASTM standards were required to accomplish this. These included changes in the pipe material designation code:

- Base resin density – 1st digit in the code
- Slow crack growth (SCG) – 2nd digit in the code
- Hydrostatic design stress (HDS) – 3rd and 4th digits in the code

a) Base Resin Density

PE 3408 materials used for water pipe applications have a base resin density about 0.944 g/cc, which is a D 3350 density cell class 3 – this is the first digit in the pipe material designation code PE 3408. Most high-performance PE 4710 materials have a base resin density around 0.950 g/cc. In order to differentiate the high performance HDPE materials from traditional HDPE materials, the density cell class of ASTM D 3350 was split to create a new density class 4 for the new high performance PE materials:

- Previous cell class 3 > 0.941 – 0.955 g/cc
- New cell class 3 > 0.941 – 0.947 g/cc
- New cell class 4 > 0.947 – 0.955 g/cc

Most high-performance HDPE materials will have a density cell class 4 based on their base resin density around 0.950 g/cc.

b) Slow Crack Growth (SCG)

Slow crack growth is the dominant field failure mode for PE pipes. Simply put, it is a crack that can develop in PE pipe and grows slowly through the pipe wall. Poor backfill, excessive surface damage, rock impingement, excessively tight bend radiuses, improper backfill and other field conditions could cause localized stress concentrations resulting in slow crack growth in polyethylene pipes. The resistance to slow crack growth is a valuable property for PE pipes.

The PENT (Pennsylvania Notch Test - ASTM F 1473) measures relative resistance to slow crack growth using a laboratory test method. A specimen is cut from a compression molded plaque. It is precisely notched and then exposed to a constant tensile stress at a temperature of 176°F (80°C). The time to failure is recorded and this failure time is related to actual service life in the field. The PENT test has proven to be a very good indicator of SCG in PE pipes.

A published paper in the Plastic Pipe VIII conference provided data which correlated laboratory PENT values to field pipe performance. Based upon this data, a laboratory PENT value of 10 to 20 hours, should correlate to a field life of at least 100 years with very few failures. PPI determined that a requirement of at least 500 hours PENT slow crack growth resistance would provide assurance that high performance PE pipes will be highly unlikely to fail in the field in the slow crack growth mode.

The current PE 3408 requirement for PENT (ASTM F 1473) performance in ASTM water pipe standards is 10 hours, which is a D 3350 SCG (slow crack growth) cell class 4 – this is the second digit in the pipe material designation code PE 3408. ASTM D 3350 was revised to add a new SCG cell class 7 for 500 hours to recognize the elevated SCG resistance of the high-performance PE materials.

- Current cell class 4 at least 10 hours
- Current cell class 6 at least 100 hours
- New cell class 7 at least 500 hours

With this change, the traditional HDPE materials will have a SCG cell class 4 or 6, where high performance PE materials will qualify for the new SCG cell class 7.

c) Hydrostatic Design Stress

The hydrostatic design stress (HDS) for PE 3408 materials is 800 psi for water at 73°F (23°C), which are the third and fourth digits in the pipe material designation code PE 3408. High-performance PE materials that meet the increased performance requirements indicated below qualify to be listed in PPI document TR-4 with a 1000 psi HDS for water at 73°F (23°C) if the PE material meets high-performance criteria as published in PPI TR-3. (Reference: Section F.7 of "Requirements For Polyethylene (PE) Materials To Qualify For A Higher Design Factor.")

1) PENT value over 500 hours
2) 23°C stress regression line substantiated to 50 years
3) LCL/LTHS ratio over 90%

High-performance PE 4710 materials that meet the additional high performance have a 1000 psi HDS (based on a design factor of 0.63), where the "10" is derived by dividing the 1000 psi HDS by 100.

As discussed above, PPI document TR-3 section F.7, “Requirements For Polyethylene (PE) Materials To Qualify For A Higher Design Factor,” states that in order for a material to qualify for a recommended PPI design factor of 0.63, the HDPE material must meet three requirements. The Dow PE 4710 selected for use in the Callaway ESW replacement piping meets all three of these requirements as demonstrated below:

1) Minimum slow crack growth performance by ASTM F 1473 of 500 hours as required by ASTM D 3350 (i.e. PENT of at least 500 hours).

    - The Dow PE 4710 material significantly exceeds this requirement for resistance to slow crack growth (i.e., PENT greater than 10,000 hours) as shown in Enclosure 1 in ULNRC-05490 (Ref. 2).

2) 50 year substantiation according to Part F.5 of TR-3.

    - The Dow PE 4710 material met this requirement as shown in Enclosure 3.

3) LCL/LTHS ratio of at least 90% as per ASTM D 2837 -Where LCL is Lower Confidence Limit - The lowest value of the LTHS, based on a statistical analysis of the regression data that can be expected at 100,000 hours.

    - The Dow PE 4710 material met this requirement (i.e. LCL/LTHS greater than 93%) as shown on Enclosure 3.

<u>Basis 3 – Reduction in Material Variability</u>

The purpose of the design factor in ASME Code is to account for the unknowns in the design and construction process. If the number and/or extent of the unknowns can be reduced, the design factor can be reduced without a reduction in safety.

In the typical design and construction of a piping system, the design is performed assuming minimum material performance requirements as defined by the Code. Furthermore, there is no limit to the number of different suppliers that can supply piping or fittings to be used in the same system. This results in an inherent amount of variability in the material properties. The design factor accounts for such variations.

The replacement Callaway ESW HDPE pipe and fitting are all being manufactured from Dow PE 4710 material. Furthermore, all piping is being manufactured in one facility from the same batch lot of resin material, and all fittings are being manufactured in one facility from the same batch lot of resin material. These facilities and processes were assessed and witnessed by Ameren to assure all identified critical characteristics for the products being supplied were acceptably controlled.

These actions implemented by AmerenUE for this project significantly reduce the extent of the unknowns associated with material variability. Although the accounting for the material variability is not removed from the design factor for PPI or Callaway, the reduction in material variability at Callaway provides additional confidence that an increase in the design factor would not constitute a reduction in safety.

Enclosure 7
to ULNRC-05517

SUMMARY OF REGULATORY COMMITMENTS

The following table identifies those actions committed to by AmerenUE in this document. Any other statements in this submittal are provided for information purposes and are not considered to be commitments. Please direct questions regarding these commitments to Mr. Scott Maglio, Assistant Manager – Regulatory Affairs, (573) 676-8719.

COMMITMENT	Due Date/Event
AmerenUE will evaluate future investigations performed by the industry to confirm the short-duration (30-day) stress allowables and applicable design factors for PE4710 piping. AmerenUE will also evaluate future evolution of the fusion technique to validate structural integrity of the installed fusion joints. The results will be submitted to the NRC prior to submittal of Callaway's fourth 10-year interval inservice inspection plan, and will include, if necessary, a fourth-interval alternative request.	Prior to submittal of Callaway's inservice inspection plan for the fourth 10-year interval.