BEFORE THE WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION

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DON F. KOPCZYNSKI

REPRESENTING AVISTA CORPORATION

Avista Utilities Asset Management

Proposed Protocol for Managing Select Aldyl A Pipe in Avista Utilities' Natural Gas System

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Proposed Protocol for Managing Select Aldyl A Pipe in Avista Utilities' Natural Gas System

Executive Summary

Avista Utilities (Avista) is proposing to undertake a twenty-year program to systematically remove and replace select portions of the DuPont Aldyl A medium density polyethylene pipe in its natural gas distribution system in the States of Washington, Oregon and Idaho. None of the subject pipe is "high pressure main pipe," but rather, consists of distribution mains at maximum operating pressures of 60 psi and pipe diameters ranging from 1¼ to 4 inches. As part of this program, Avista will re-make connections of select Aldyl A service piping, ½ and ¾ inch diameters, where tapped to steel main piping. Further, Avista notes that while there have been concerns with the integrity of steel pipe in other parts of the country in recent years, the steel pipe in its system, including steel service risers, is being managed to protect its long-term reliability and performance and is outside the scope of this program.

In recent years, Avista experienced two incidents on its natural gas system that prompted the Washington Utilities and Transportation Commission and the Company to better understand the potential long-term reliability of Aldyl A pipe. Results of these investigations, which were aided by new tools developed for Avista's Distribution Integrity Management Plan ("DIMP" or "Integrity Management"), corroborated reports for similar Aldyl A piping around the country as supporting the development of a protocol for the management of this gas facility. The following report highlights the history of DuPont's Aldyl A natural gas pipe and summarizes DuPont and Federal Agency communications that are relevant to this proposed program. The report documents the Aldyl A pipe in Avista's natural gas system and describes the analysis of the types of failures observed in this pipe, and the evaluation of its expected long-term integrity. Finally, the report describes the results of Avista's work to establish the framework for the proposed protocol for the management of Aldyl A pipe in its natural gas system.

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I. History of DuPont Aldyl A Piping Systems

Modern polyethylene pipe products are corrosion-free, lightweight, cost-effective, highly-reliable, and can be installed quickly and efficiently. For these reasons, it has for decades been the 'standard for the industry' and is the predominant choice used in natural gas distribution systems. As with any revolutionary product line, polyethylene piping systems have undergone continuous and rigorous testing and product improvement. Such is the case with DuPont's Aldyl A piping systems, as very briefly summarized below.

DuPont Introduces Natural Gas Polyethylene Pipe – 1965

Along with other manufacturers, DuPont began to use polyethylene resin to produce plastic piping for a variety of purposes. The resin was produced from ethylene molecules combined together in repeating patterns to form larger molecules called 'polymers', hence the name 'polyethylene.' DuPont's product designed specifically for use in the natural gas industry was marketed under the name "Aldyl A." The initial resin used in production of Aldyl A pipe, Alathon 5040, was manufactured from 1965 to 1970. DuPont changed the resin in 1970 to improve Aldyl A's resistance to rupture during pressure testing. This improved formulation, known as Alathon 5043, was the primary resin used in DuPont's Aldyl A pipe from 1970 until 1984.

The Phenomenon of "Low Ductile Inner Wall"

Shortly after changing its polyethylene resin in 1970, DuPont detected a manufacturing issue highlighted during laboratory testing of Aldyl A pipe. DuPont learned that its manufacturing process was resulting in some of the pipe having a property described as "Low Ductile Inner Wall." "Ductility" is the ability of a material to withstand forces that alter its shape without it losing strength or breaking. A 'highly-ductile' material can be bent, flexed, pressed or stretched without cracking or losing strength because, unlike brittle materials, it can redistribute the forces of stress concentration. Low Ductile Inner Wall, or as it often appears "LDIW," results when the inner surface of the Aldyl A pipe becomes brittle, promoting the formation of cracks and premature failure. In early 1972, DuPont changed its manufacturing process to eliminate this phenomenon, but estimated that 30 – 40% of the pipe it produced in 1970, 1971 and early 1972 was affected, primarily in pipe diameters from 1¼ inches to 4 inches.

DuPont Communicates Potential Issues to Aldyl A Customers

1982 Letter

In 1982, DuPont sent a letter to its natural gas customers, noting that two of its gas utility customers had reported a low frequency of leaks in Aldyl A pipe manufactured prior to 1973 (See Attachment 1). These leaks were reported as "slits" occurring where the pipe was in "point contact with rocks." DuPont noted these two utilities had increased the frequency of leak surveys where rock may have been part of the backfill around the pipe, and encouraged other Aldyl A customers to consider the same. This letter was the genesis of what would become a continuing focus on the pipe vintage known as "pre-1973 Aldyl A."

1986 Letter

DuPont's second letter to its Aldyl A pipe customers was sent in 1986, focusing again on pre-1973 Aldyl A pipe (See Attachment 2). The letter focused on results of newly-developed (elevated temperature) testing methods that allowed DuPont to more-accurately estimate the longevity of this vintage pipe, in diameters of 1¼ inches and larger. Test results showed that 'Aldyl A pipe manufactured prior to 1973 had certain limitations that were not previously-shown by then-available, state-of-the-art testing methods.' The limitations were described as a reduction in pipe service life caused by: 1) "rock impingement" or pressure from rock points directly on the pipe (as mentioned in their 1982 letter), and 2) the use of squeeze-off practices. The term "squeeze-off" refers to the current and long-standing construction practice of mechanically pressing in polyethylene pipe walls to temporarily stop the flow of gas during work on a line that is in service. DuPont further noted that average ground temperature surrounding the pipe, in the ranges of 60 to 70 degrees (F), had a major bearing on its ultimate expected service life. Finally, DuPont recommended that operators should reinforce the pipe, using clamps that surround the pipe at squeeze points, in order to extend the life of its Pre-1973 Aldyl A.

DuPont Substantially Improves Aldyl A Pipe

DuPont made a significant change to its Aldyl A resin formulation in 1984. The improved resin, known as Alathon 5046-C, was marketed as "Improved Aldyl A", and significantly improved the performance of Aldyl A pipe in its resistance to 'Slow Crack Growth' and overall long-term integrity. Slow Crack Growth, or as it's often abbreviated, SCG, describes the progression of a crack that begins with 'crack initiation' or the formation of a crack in the inner wall of the pipe. The crack then progresses through the pipe wall, usually over period of many years, until it finally breaks through the outer surface of the pipe, resulting in failure.

Again, in 1988, DuPont announced another advance in its Aldyl A pipe resin with the introduction of Alathon 5046-U. This change in resin formulation increased the resistance of the pipe to slow crack growth by another order of magnitude. In addition, because of the high 'molecular efficiency' of this new resin, its density was also reduced, which allowed for much greater ductility in the pipe. This product, the last of the DuPont Aldyl A materials that Avista would install, was also marketed as Improved Aldyl A. A summary of DuPont Aldyl A pipe produced between 1965 and 1992 is presented below in Table 1. Information includes the year of manufacture, resin formulation, relative resistance to slow crack growth (stress rupture testing at 80° C / 120 psig for accelerated life testing), and summary notes.

Table 1. DuPont Aldyl A Pipe 1965 - 1992

Years of Manufacture	Resin	Rupture Resistance*	Notes
1965 - 1970	Alathon 5040		Initial Product Marketed as "Aldyl A"
1970 - 1972	Alathon 5043	10 hours	Resin Improvement and Low Ductile Inner Wall
1970 - 1984	Alathon 5043	100 hours	Resin Improvement
1984 - 1988	Alathon 5046-C	1000 hours	Resin Improvement-- Sold as "Improved Aldyl A"
1988 - 1992	Alathon 5046-U	10,000 hours	Resin Improvement --"Improved Aldyl A"

*Illustrates the order of magnitude difference found from accelerated life testing of resins

Common Classifications of Aldyl A Pipe

Based on the characteristics of the different vintages of Aldyl A pipe, there would emerge over time, from DuPont's 1982 letter going forward, three age-groupings recognized by the manufacturer, natural gas industry, and regulators as relevant in the reliability management of this pipe.

Pre-1973 Aldyl A – Pipe manufactured through 1972, from the first two resin formulations, and including pipe having low ductile inner wall.

Pre-1984 Aldyl A – Aldyl A pipe manufactured from Alathon 5043 resin, but only that pipe manufactured after 1972 and through 1983.

1984 and Later Aldyl A – Pipe manufactured from the improved Alathon 5046-C and 5046-U resins.

Aldyl A Service Pipe - Small-diameter (less than 1¼ inches) Aldyl A service piping is often treated or managed differently than larger-diameter Aldyl A pipe of the same vintage. This is because the small-diameter pipe has been assessed by industry experts as being more resistant to brittle-like cracking than larger-diameter pipe due to its greater flexibility. Further, small-diameter Aldyl A pipe has been confirmed as being free of the Low Ductile Inner Wall properties present in late 1970 through early 1972 vintage piping.

II. Federal Bulletins on Brittle-Like Cracking in Plastic Pipe

National Transportation Safety Board

In April 1998, twelve years after DuPont's second letter to customers, the National Transportation Safety Board (Board) published a comprehensive safety bulletin describing their investigation of natural gas pipeline accidents involving polyethylene pipe that had cracked in a "brittle-like" manner (See Attachment 3). The bulletin focused primarily on accidents related to an early plastic pipe manufactured by Century Utility Products (Century), produced from Union Carbide resin. In its review, findings, and in its Safety Recommendations, however, the Board concluded that in addition to the Century pipe, much of the polyethylene pipe produced for gas service from the 1960s through the early 1980s may be susceptible to brittle cracking and premature failure, further noting that vulnerability of this material to premature failure could represent a serious potential hazard to public safety.

The Board's bulletin represented a seminal work on the vulnerability of early plastic pipe to brittle-like cracking because it analyzed and integrated – for the first time – reports from the technical literature, manufacturers' communications, industry expert opinions, the experience of pipeline operators and regulators' accident reports. Because the bulletin provided a clear understanding of the drivers of failure in older polyethylene pipe, we have included a fairly detailed synopsis in this report.

Objectives of the Board's Investigation

Following the Board's investigation of over a dozen serious incidents, it undertook an effort to evaluate whether the existing pipeline accident data was sufficient for assessing the long-term performance of plastic piping. The office of Research and Special Programs Administration of the National Transportation Safety Board compiled the relevant accident data, but found it to be insufficient for this purpose. Lacking adequate data for the larger assessment, the Board instead focused on estimating the likely frequency of brittle-like cracking, focusing on published technical literature, industry expertise, and work with several gas system operators. From this review, the Board launched a special investigation with the objectives to address three safety issues related to polyethylene gas service pipe:

1. Vulnerability of plastic piping to brittle-like cracking
2. Adequacy of available guidance to pipeline operators regarding installation and protection of plastic pipe tapped to steel mains
3. Performance monitoring as a possible way to detect unacceptable performance in piping systems

Phenomenon of Premature Brittle-Like Cracking

The Board's survey suggested that early plastic piping may be "susceptible to premature brittle-like cracking under conditions of stress intensification." The term 'stress intensification' refers to localized pressure on the pipe wall created by such conditions as rock contact or significant bending of the pipe. The phenomenon of brittle-like cracking was characterized by the failure processes described above, beginning with the initiation of cracks on the inner wall of the pipe at the pressure or stress point, followed by slow crack growth that progressed under normal pipeline operating pressures (much lower than the pressure required to rupture the pipe). The process culminated with the crack reaching the outside wall of the pipe, showing up as a very tight, slit-like opening on the surface, running generally parallel with the length of the pipe. Premature brittle-like cracking was believed, at the time of the Board's safety bulletin, to require relatively high and localized stress on the pipe resulting from sharp or excessive bending, soil settling, rock "impingement" (point or contact pressure on the pipe), improperly installed fittings, and dents or gouges to the pipe surface. The term 'brittle-like cracking' was used to describe this failure process because the pipe showed no signs of being bulged or deformed where the cracks occurred.

Board Findings on the Three Identified Safety Issues

Issue 1: Vulnerability of Plastic Piping to Brittle Cracking

Long-Term Strength of Early Pipe was Overrated - In the early 1960s the industry had very little long-term experience with plastic pipe, and consequently, developed laboratory testing procedures to forecast the expected service life of piping. Early testing results suggested that polyethylene pipe would exhibit a relatively constant, or 'straight line' gradual decline in strength over time. These tests and underlying assumptions were subsequently incorporated as standards for the industry and in related federal requirements.

As the industry gained experience, however, the straight-line assumptions of these early procedures began to be challenged through the development of new testing methods, where pipe strength was assessed under conditions of elevated temperature (such as the testing referenced in DuPont's 1986 letter to customers). Results of the elevated-temperature testing showed that the decline in strength of early plastic pipe was not gradual or linear as had been assumed, but instead, began to accelerate or drop below the straight line, especially after twelve years. The Board concluded that the early testing procedures may have overrated the strength and resistance to brittle-like cracking of the polyethylene pipe manufactured for the gas industry from the 1960s through the early 1980s.

Long-Term Ductility was Overrated - Another important assumption about early plastic pipe, based on short-term testing, was that it would retain its ductile properties long term. The assumption of long-term ductility had important safety ramifications since it allowed plastic pipe systems to be designed to withstand stresses generated primarily by internal pressure and to give less consideration to the impacts of external stresses such as bending. Unfortunately, the early testing methods did not properly identify the evidence of the "ductile to brittle" transition that was occurring early in the life of the pipe. Consequently, the tests did not distinguish pipe failures resulting from a loss in ductility. The Board noted that this loss of ductility was also observed in the older piping of several manufacturers, those other than Century Utility Products.

Pipeline Operators had Insufficient Notification - The Board noted that premature brittle-like cracking was a complex phenomenon that had not been systematically communicated to the industry, and hence, had not been fully-appreciated by pipeline operators. The Board recognized pipe manufacturers as commonly offering technical and safety assistance to operators, and occasionally, formal reports on their materials. But, because the information on the potential weakness of their products was also mixed with information publicizing its best performance characteristics, the message was not clear. The Board also noted that the Federal Government had not provided relevant information to gas system operators, and concluded that operators had insufficient notification that much of their early polyethylene pipe may have been susceptible to premature brittle-like cracking. Finally, the Board went on to recommend that the polyethylene pipe manufacturers' organization, the Plastics Pipe Institute, advise its members to notify pipeline operators if any of their materials indicate poor resistance to brittle-like failure.

Issue 2: Adequacy of Guidance for Connecting Plastic Pipe to Steel Mains

Critical Understanding of Stress on Pipe - The Board observed that the premature transition of plastic piping from a ductile to a brittle state appeared to have little observable adverse impact on the serviceability of plastic pipe, *except* where the pipe was subjected to external stresses, such as excessive bending, earth settlement, dents or gouges to the pipe surface, and improper installation of fittings, etc. Of those sources of stress, a key factor identified in the Board's bulletin was earth settlement, but particularly in cases where plastic piping was connected to more rigidly anchored fittings, such as steel main pipe. Because the physical properties of plastic and steel respond differently under the same conditions, such as to temperature change and ground settlement, the slight movements of each type of pipe in the ground will be different. This difference in movement can result in significant stress at the point of connection between the plastic and steel piping.

Much of the Guidance to Operators was Insufficient or Ambiguous - In addition to pipeline operators having insufficient guidance on the overall issue of the vulnerability of plastic pipe to brittle cracking, as noted above, the Board also observed that much of the available guidance to operators on how to limit stress on the pipe during installation was inadequate or ambiguous. This was particularly the case with the stress associated with the tapping of plastic service piping to steel mains, where the Board concluded that many of those connections may have been installed without adequate protection from external stress. The Board went on to identify several instances where safety requirements did not fully incorporate safety recommendations, resulting in ambiguity for pipeline installers and regulators. Other highlights of the Board's findings were the many cases where the applicable regulations applying to pipeline installation lacked any performance measurement criteria. Noting that the Office of Pipeline Safety considered many of its safety regulations to be performance-oriented requirements, the Board rebutted this in stating that “many are no more than general statements of required actions that do not establish any criteria against which the adequacy of the actions taken can be evaluated.” A particular example was the regulation that “requires gas service lines to be installed so as to minimize anticipated piping strain and external loading,” and yet it contained no performance measurement criteria for establishing compliance. Finally, the Board went on to note cases where the inadequacy of pipe manufacturers’ instructions also contributed to the lack of a clear understanding of methods to limit stress on plastic pipe during installation.

Issue 3: Monitoring of Plastic Pipe to Determine Unacceptable Performance

The Board’s final objective was focused on performance monitoring of pipeline systems as the key to effectively managing the vulnerable piping types identified in the bulletin. In this discussion, the Board focused on the accident in Waterloo, Iowa in 1994[1], in highlighting the very real challenges of designing effective pipeline monitoring programs. The Board stated that before the accident, the pipeline operator had developed a limited capability to monitor and analyze the condition of its system. It concluded however, that the systems the operator had developed for tracking, identifying, and statistically treating plastic piping failures did not permit an effective analysis of system failures and leak history, noting that their methods of handling of pipe data masked the high failure rates of the subject Century pipe. While the operator did re-evaluate its monitoring data after the accident, and subsequently identified the high failure rates of Century Pipe, the Board opined that the problem could have been detected earlier (before the accident) if the data had been properly analyzed in the first place. Finally, the Board concluded that an effective monitoring program would have allowed the operator to implement a pipe replacement program that might have prevented the accident.

In the second case, the Board noted that while the operator had added capabilities to its pipe-monitoring protocols, it had still not chosen parameters needed to provide adequate analysis of its plastic piping system failures and leak history. The bulletin went on to note examples of the many types of additional parameters needed to enable the effective tracking, identifying, and properly describing system failures and leak history.

The Board concluded that in light of the key findings in its bulletin, that gas system operators may need to be advised once again of the importance of complying with Federal requirements for piping system surveillance and analyses. Regarding the monitoring of older piping, the Board identified the necessity to analyze factors such as piping manufacturer, installation date, pipe diameter, operating pressure, leak history, geographical location, modes of failure, location of failure, etc. Finally, the Board noted that an effective monitoring program would require the evaluation of pipe material and installation practices to provide a basis for the planned and timely replacement of piping that indicates unacceptable performance.

[1] In October, 1994, a natural gas leak and explosion at Midwest Gas Company in Waterloo, Iowa, resulted in 6 fatalities and 7 injuries. The cause of the incident was identified as the failure of a ½ inch diameter service pipe cracking in a brittle-like manner at a connection to a steel main.

Pipeline and Hazardous Materials Safety Administration

1999 Bulletins

The first two of several advisory bulletins related to the Board's 1998 Safety Bulletin (above), were published by the Office of Pipeline Safety, now known as the Pipeline and Hazardous Materials Safety Administration (Administration), in March 1999 (See Attachment 4). The bulletins, which were issued as advisories to pipeline owners and operators, provided an abstract of the findings of the Board's 1998 investigation and advised that much of the plastic pipe manufactured from the 1960s through the early 1980s may be susceptible to brittle-like cracking. The advisories concluded with the recommendation to owners and operators to identify all pre-1982 plastic pipe installations, analyze leak histories, evaluate potential stresses to pipe, and to develop appropriate remedial actions, including pipe replacement, to mitigate any risks to public safety.

2002 Bulletin

This bulletin, as with the prior advisories, reiterated to natural gas pipeline owners and operators the susceptibility of older plastic pipe to premature brittle-like cracking (See Attachment 5). But, for the first time, this advisory specifically named DuPont's pre-1973 Aldyl A pipe (Low Ductile Inner Wall) as being susceptible to brittle cracking. The bulletin also depicted several environmental and installation conditions that could lead to premature, brittle-like cracking failure of the subject pipe, and described recommended practices to aid operators in identifying and managing brittle-like cracking problems.

2007 Bulletin

This bulletin, again, served to review and recap the findings of the prior bulletins, advising natural gas system operators to review the earlier statements (See Attachment 6). In addition, the advisory recapped results of the ongoing effort of the American Gas Association to identify trends in the performance of older plastic pipe. The advisory reported that the data, at that point, could not assess failure rates of individual plastic pipe materials, but did support what was historically known about the susceptibility of older plastic piping to brittle-like failure, including the addition of specific materials to the list, such as Delrin insert tap tees.

III. 2009 Distribution Integrity Management Program

The Administration published the final rule establishing integrity management requirements for gas distribution pipeline operators in December 2009. Though the effective date of the rule was February 2010, operators were given until August 2011 to write and implement their Distribution Integrity Management Plan.

Objectives and Approach

Among other objectives, the program was intended to overcome two key weaknesses in pipeline safety management that were identified in the National Transportation Safety Board's 1998 bulletin (above): 1) correct weaknesses in federal regulations, particularly in the Office of Pipeline Safety, by establishing true measurement criteria for establishing safety compliance, and 2) establish systematic protocols for pipeline data collection, analysis, and interpretation, that helps ensure accurate integrity assessment and appropriate remediation.

The concept of Integrity Management grew out of a demonstration project of the Office of Pipeline Safety designed to test whether allowing operators the flexibility to allocate safety resources through risk management was effective in improving pipeline safety and reliability. Integrity management requires operators, such as natural gas distribution companies, to write and implement Integrity Management Programs (IMPs) to assess, evaluate, repair and validate the integrity of pipeline segments. The program contains the following elements:

- Knowledge
- Identify Threats
- Evaluate and Rank Risks
- Identify and Implement Measures to Address Risks
- Measure Performance, Monitor Results, and Evaluate Effectiveness
- Periodically Evaluate and Improve Program
- Report Results

The Integrity Management approach uses historical leak data and other facility information, along with the input of subject-matter experts, to identify individual threats to a gas system. These threats are then analyzed to predict the likelihood and consequences of failure. Each threat is then ranked by priority, followed by the development of a plan to reduce or remove those risks as deemed necessary.

IV. 2011 Call to Action – Transportation Secretary LaHood

Finally, in April 2011, U.S. Transportation Secretary LaHood issued a Call to Action to all pipeline stakeholders in conjunction with the effective application of the Distribution Integrity Management Program (See Attachment 7). The Call to Action was aimed at the more than 2.5 million miles of liquid and gas pipelines of both federal and state jurisdiction, including transmission and distribution facilities, calling on owners and operators, the pipeline industry, utility regulators and state and federal partners to:

- Evaluate risks on pipeline systems;
- Take appropriate actions to address those risks, and
- Requalify subject pipeline systems as being fit for service.

The centerpiece of the Call to Action is the "Action Plan" of the Board and Administration. The focus of the Action Plan is to accelerate the rehabilitation, repair, and replacement of high-risk pipeline infrastructure, calling on pipeline operators and owners to take "aggressive efforts… to review their pipelines and quickly repair and replace sections in poor condition." To buttress this Call to Action, Secretary LaHood has asked Congress to increase maximum civil penalties for pipeline violations, to close regulatory loopholes, strengthen risk-management requirements, add more inspectors, improve data reporting and help identify potential pipeline safety risks early.

V. Avista's Experience with DuPont Aldyl A Piping Systems

Avista has approximately 12,500 miles of natural gas piping in its service territories in the States of Washington, Oregon and Idaho. Like dozens of other gas utilities, Avista adopted plastic pipe as an excellent alternative to steel, and consequently, the broad majority of Avista's pipe is polyethylene (about 8,500 miles) of various types, ages and brands, including DuPont's Aldyl A.

Avista began installing DuPont Aldyl A in 1968 and discontinued its use in 1990 when DuPont sold their production to Uponor. Of the various vintages and formulations of Aldyl A pipe in its system, Avista has estimated quantities in the following amounts, in diameters of ½" to 4":

Pre-1973 Aldyl A (1965-1972 resins)	190 Miles
1973-1984 resins	960 Miles
1985-1990 resins	919 Miles

Avista noted the advisory bulletins of the Board and Administration in 1998, 1999 and 2002, but since it had no documented trends in the types of failures highlighted, continued to manage its Aldyl A pipe according to established monitoring standards for leak survey and sound operations practices.

Spokane and Odessa Incidents

In recent years, however, Avista experienced two natural gas incidents[2] resulting in injuries and property damage that signaled possible changes in leak patterns in its Aldyl A piping. The first incident occurred in 2005 at a commercial site in Spokane. This event involved the failure of 1976-vintage Aldyl A pipe caused by bending-stress resulting from poor soil compaction around the pipe that was performed by a non-Avista excavator in 1993. The post-incident investigation judged the resulting leak to be an anomaly that could have been prevented with proper care by that third-party excavator.

[2] The Pipeline and Hazardous Materials Safety Administration defines a natural gas "incident" as a release of gas that results in any of the following: a fatality or personal injury that requires in-patient hospitalization; property damage of $50,000 or greater, or the loss of greater than 3 million cubic feet of gas.

The second incident, at a residence in the town of Odessa, Washington, in late 2008, was determined to be the result of rock pressure on the 1981-vintage Aldyl A pipe that occurred during the initial installation. Avista signed a settlement agreement with staff of the Washington Utilities and Transportation Commission as an outcome of the investigation of this incident. Under terms of the agreement, which was subsequently approved by the Commission, Avista increased the frequency of its residential leak survey on pre-1984 resin (pre-1987 installed) Aldyl A natural gas mains in its Washington jurisdiction, from once every five years to annually. In addition, whenever it is excavating in the vicinity of Aldyl A natural gas mains in Washington, Avista will also report on the soil conditions surrounding the pipe, and identify appropriate and reasonable remedial measures, as necessary. Avista retained the consulting services of Dr. Gene Palermo to help develop its approach for managing Aldyl A pipe, in relation to the soil conditions reported.

Expert-Recommended Protocol for Managing Aldyl A Pipe in Relation to Reported Soil Conditions

Dr. Palermo is a nationally-recognized expert on the plastic pipe used in natural gas systems, and in particular, Aldyl A piping. He has worked in the plastic pipe industry for over 35 years, which includes 19 years with the DuPont Corporation in its Aldyl A natural gas pipe division.

Dr. Palermo also served as the Technical Director for the Plastics Pipe Institute from 1996 through 2003 and served on the Institute's Hydrostatic Stress Board for over 20 years. Dr. Palermo has served on a variety of gas industry committees, has trained gas industry practitioners and regulators, and has received numerous awards of merit for his outstanding individual contribution to the natural gas plastic-piping industry. He is the only person to receive both the American Society of Testing and Materials - Award of Merit, and the American Gas Association - Platinum Award of Merit. Dr. Palermo is president of his consulting firm, Palermo Plastics Pipe Consulting.

Dr. Palermo reviewed the content of Avista's settlement agreement with the Commission to become familiar with its requirements, specifically with regard to managing Aldyl A piping found in soils that would currently not meet standard criteria for bedding and backfill. Dr. Palermo's review and expertise provided the basis for his recommended protocol for management of Avista's Aldyl A piping found in rocky soils. (See Attachment 8):

1. All Aldyl A pipe manufactured prior to 1984 should be evaluated for replacement in the following manner:
    a. If the pipe has Low Ductile Inner Wall properties, Avista should immediately begin a prioritized pipe replacement program.
    b. If the pipe is installed in soil with rocks larger than ¾ inch, Avista should immediately begin a prioritized pipe replacement program.
    c. If the pipe is installed in sandy soil or in soil with rocks up to ¾ inch in size, the pipe should remain in service and normal leak surveys per DOT Part 192 should be followed.

2. All Aldyl A pipe manufactured during or after 1984 should also be evaluated.

    a. If the pipe is installed in soil with rocks larger than ¾ inch in size, Avista should evaluate the pipe and consider replacing it if they begin to experience rock impingement failures, and should conduct leak surveys more frequently than required by DOT Part 192, until replacement.
    b. If this pipe is installed in sandy soil or in soil with rocks up to ¾" in size, the pipe should remain in service and normal leak surveys should be followed.

Evaluation of Leak Survey Records

Following the Odessa incident, Avista was also asked to review five years of leak survey records in Washington State to look for possible emerging patterns in the health of its Aldyl A piping system. Avista organized the leak survey information and then conducted several evaluations, which were organized under three general objectives, listed below.

1. Analyze the modes or observed types of failures in Aldyl A pipe;
2. Forecast the expected long-term integrity of Aldyl A piping;
3. Identify potential patterns in the overall health of this piping to aid in the design of a more-focused management protocol for Aldyl A pipe.

Avista used newly-available asset-management tools to conduct these assessments, including its recently-implemented Integrity Management approach for identifying and analyzing potential threats to its natural gas system. This approach is suited for just such an analysis, having the capability to determine potential patterns in the overall health of a piping system that might not have been otherwise evident through conventional data review. The analysis of the historic leak survey data, including the observation of several new Aldyl A material failures and leaks, did point to the development of a possible trend.

Pipe Replacement Projects in 2011

Another outcome of this heightened focus on Aldyl A leaks was Avista's decision to replace several thousand feet of its Aldyl A main in 2011. In Odessa, Avista increased the frequency of leak surveys on its gas system to once per quarter and mobilized a pipe replacement program that removed all of the pre-1984 Aldyl A main pipe from the gas system in the town. During that project, which was conducted from June to December 2011, nearly 32,000 feet of Aldyl A main pipe were replaced. Other Aldyl A replacement projects in 2011 removed an additional 7,000 feet of this priority pipe. Together, these projects had a capital cost of approximately $2.7 million.

VI. Avista Distribution Integrity Management Program

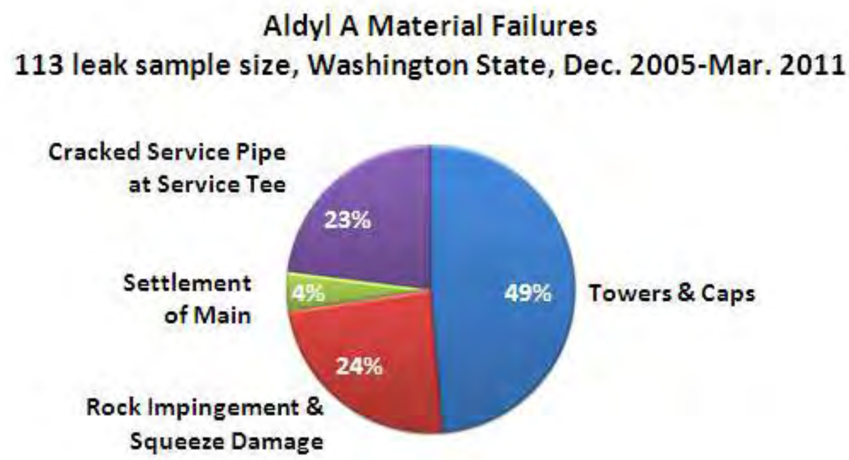
As described briefly above, the Integrity Management approach, now required by law, begins with the aggregation of historical leak-survey data and other facility information relevant to Avista's natural gas piping system. Then, in conjunction with the input of subject matter experts, individual threats to Avista's gas system are identified. These threats are analyzed to predict the likelihood and consequences of failure associated with each threat, based on the specific operating environment, system makeup, and history of Avista's natural gas system. Each threat is then ranked relative to all others to identify, by priority, those with the greatest hazard potential. From that priority list, measures are developed to reduce or remove those risks as deemed necessary. These mitigating measures are often referred to as "accelerated actions" because they may be above and beyond the minimum requirements of applicable federal and state codes. These accelerated actions can range from increased frequency of maintenance and leak surveys to full replacement programs for certain gas facilities. Finally, the mitigating measures will be reviewed to evaluate their effectiveness in reducing threats to the gas system, and the program will then be adjusted as necessary based on those outcomes.

Integrity Management requires the use of geographically-based analytical software to complete many of the required program elements. Like many utilities, Avista is using the Geographic Information System (GIS) platform developed and supported by Environmental Systems Research, Inc. (ESRI), as the geographic and analytical engine for conducting its gas system evaluations under the Integrity Management program. ESRI is a pioneer and world leader in developing and supporting geographic software products for a broad range of global business sectors, including utilities. Since Avista had already created a comprehensive GIS layer, or database, for its gas facilities, it made sense to add analytical capabilities to this platform in complying with the Integrity Management program requirements.

VII. Analyzing Modes of Failure in Avista's Aldyl A Pipe

In tackling the first objective of the assessment of its Aldyl A piping, Avista aggregated the gas leaks resulting from Aldyl A material failures found in its gas system in Washington State from late 2005 through March 2011. The sample included 113 material failures that were evaluated and summarized by component to offer an understanding of the specific failure modes for Aldyl A pipe. The 'modes' or types of material failures categorized are shown below in Figure 1.

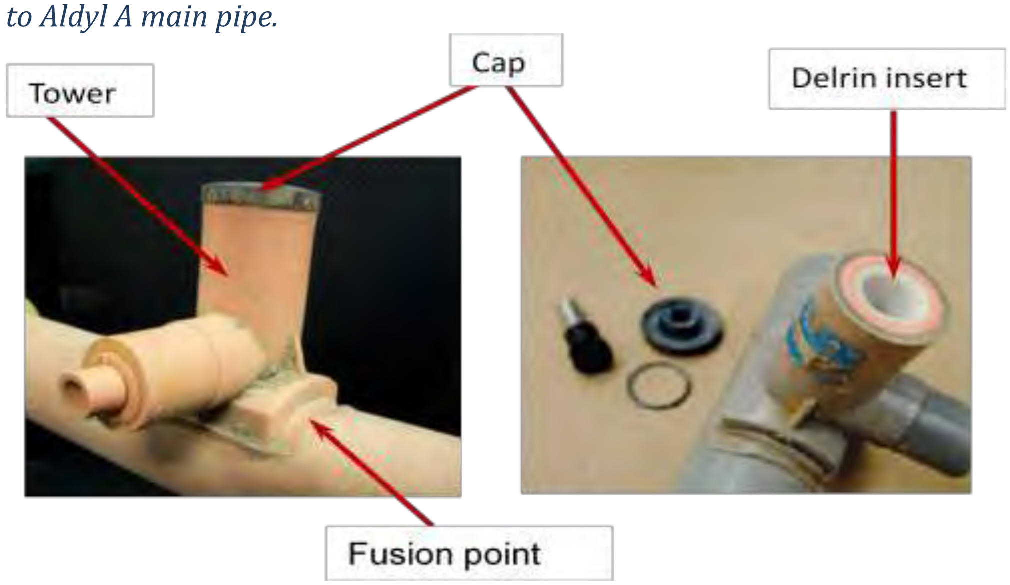
Figure 1. Modes or types of material failures documented in a sample of 113 leaks in Avista's Aldyl A piping in Washington State, December 2005 through March 2011.



Towers and Caps

The largest percentage of material failures in the sample occurred in Towers and Caps, referring to failure of the service tapping tee itself, shown below in Figure 2. In these cases, the pressure applied to the tee as the cap was tightened onto the body during initial installation has resulted in slow crack growth and failure of the tower body, the cap, or the Delrin® insert many years later. Additionally, the saddle fusion point of the tower to the main pipe is another frequent point of failure in this assembly. The unavoidable stresses created during standard installation (using factory recommended procedures) have led to brittle cracking in these components many years later. This phenomenon clearly demonstrates the susceptibility of certain resins of Aldyl A piping to tend to fail by brittle cracking due to the slow crack growth initiated during installation.

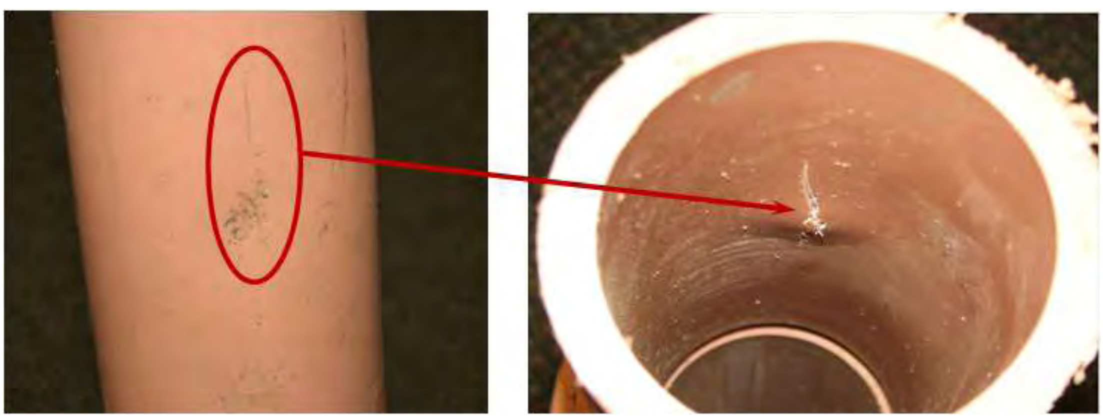
Figure 2. External features and internal components of a typical Aldyl A service tee, as fused to Aldyl A main pipe.



Rock Contact and Squeeze-Off

The second-most common material failure observed in Avista's Aldyl A pipe was due to localized, brittle cracking in Aldyl A mains that resulted from rock impingement – rock pressure directly on the pipe, or places where 'squeeze-off' was applied over the pipe's service life. These failures are very typical for certain resins of Aldyl A main pipe, having been consistently reported by other utilities since before the time of DuPont's 1986 letter. As described earlier, when these external stresses (rock impingement or squeeze-off) cause the pipe to fail, it always begins with crack initiation on the inside surface of the pipe wall, eventually resulting in slow crack growth that propagates toward the outer wall of the pipe, and finally, through-wall failure. These failures generally appear as short, tight cracks in the outer wall of the pipe that run either parallel, or slightly off-parallel with the length of the pipe. A typical failure in Aldyl A main pipe, showing a crack through the pipe wall as it appears on both the inner and outer surfaces, is shown below in Figure 3.

Figure 3. Typical brittle-like crack through the wall of Aldyl A pipe, resulting from rock contact directly on the pipe.



Although the duration of the stress caused by rock contact with the pipe is very different from that associated with squeeze-off, they both result in the same pattern of crack initiation and slow crack growth leading to failure of the pipe. Other sources of external stress that can result in brittle failure of Aldyl A pipe, as mentioned earlier in the report, include bending of the pipe, soil settlement, dents or gouges to the pipe, and improper installation of fittings.

Services Tapped from Steel Mains

The third most-common failure in Avista's sample occurred where small diameter Aldyl A service pipe is tapped from steel main pipe. In this application, a steel service tee is welded to the steel main pipe and the small-diameter Aldyl A service pipe is then connected to a mechanical transition fitting on the tee, as pictured below in Figure 4.

Figure 4. Typical polyethylene service tapped from a steel main.

It is at this transition point, between the rigid steel fitting and the more-flexible Aldyl A service pipe, that brittle-like cracking has been observed. This failure mode in older plastic pipe is well understood, and was one of the three study objectives reported by the National Transportation Safety Board in its 1998 bulletin, summarized earlier in this report.

Avista's Aldyl A Services

Avista believes its Aldyl A "service" piping, apart from cracking at the connection with the tee on steel main pipe, has no greater tendency to fail than its other polyethylene service piping, and at this point in time, should not be managed differently than other plastic service pipe (frequency of leak survey, etc.). Consequently, Avista is not planning to systematically replace Aldyl A service pipe as it replaces main pipe and rehabilitates service connections at steel tees. Avista is using the Integrity Management model, however, to track and analyze service leaks going forward to determine if the reliability of Aldyl A service piping changes in ways that warrant a different approach.

Understanding the Significance of Leaks in Aldyl A Pipe

Frequency and Potential Consequence

Analysis of the material failures of Aldyl A pipe provides the opportunity to put these leaks into perspective with other types of leaks on Avista's natural gas system. As part of the development of the Integrity Management Plan, five years of leak data were analyzed for Avista's three-state service territory. The data included nearly 17,000 individual leaks, which were categorized according to the underlying threats to the natural gas system as required under Integrity Management. As a point of comparison of the significance of leak types, the data included in excess of 2,000 leaks associated with the failure of gas system equipment, such as valves, fittings and meters. Only 153 leaks, however, were identified as resulting from 'material failures' of Aldyl A piping in the three states. Looking simply at Aldyl A leaks as part of the aggregate of all system leaks, one might conclude that Aldyl A pipe failures pose a limited potential for hazard relative to the threat of other system leaks. In fact, while gas equipment leaks are more likely to occur, their potential consequence is often minimal. A thorough understanding of this difference is one of the most important requirements and outcomes of any effective Integrity Management Plan analysis.

Review of the leak-history data shows the vast majority of equipment leaks as occurring typically with shut-off valves and gas meters, located either above ground or in locations that allow free-venting of gas to the atmosphere. Consequently, these types of leaks have a low potential to result in an incident posing harm. Through public awareness programs, people have become familiar with the odor of venting gas and tend to quickly call Avista to make repairs; this is especially true if the venting gas can be associated with visible gas valves or meters. By contrast, Aldyl A failures and the associated leaks occur almost entirely underground, out of sight, often in populated areas, and occasionally in the proximity of buildings that are not actually connected to the natural gas system. Without visible facilities, natural gas may have an unexpected presence in the environment that allows people to dismiss slight gas odors. This reduced awareness allows gas from these undetected leaks to have the significant potential to migrate into buildings before it can be identified and reported. This is especially true in winter when the ground is saturated, frozen or snow covered, and in areas of full pavement and concrete finishes. Of the roughly 2,000 equipment leaks reported in the five years of data reviewed, none resulted in gas incidents. By comparison, two of the relatively-small number of Aldyl A material failures resulted in gas migrating into buildings undetected, and upon accidental ignition, resulted in harmful incidents.

The Complication of Brittle Cracking in Aldyl A Pipe

The common mode of failure for Aldyl A materials, brittle-like cracking, can also present special problems compared with leaks in other gas piping, such as corrosion in steel gas pipe. Corrosion leaks tend to begin with the failure of a very minute area in the pipe wall, which then begins to release a very minute amount of natural gas. These leaks then tend to progress very slowly and in a stable and somewhat predicable way over time. These types of leaks, while never positive, are more likely to be detected by modern gas-detection equipment when they are at a stage where the release of gas is relatively minor. By contrast, leaks in Aldyl A piping tend to first appear as substantial (high gas volume) leaks that appear in a very short time period. This is due to the nature of brittle cracking, where the crack can progress very slowly from the inner wall of the pipe toward the outer wall without any release of gas, until the pipe finally splits open, resulting in a substantial failure. Additionally, unlike the prevention or even suspension of corrosion problems in steel pipe through effective protection methods, there is no way to halt undetected progress of slow crack growth in brittle Aldyl A pipe.

VIII. Reliability Modeling of Avista's Aldyl A Piping

Avista's Asset Management Group performed reliability modeling for several classes of its natural gas pipe in order to assess the long-term performance of its Aldyl A piping, compared with steel pipe and newer-vintage plastic pipe. Reliability analysis comes from the discipline of 'reliability engineering' and is a foundational asset management tool that provides a forecast or prediction of the future performance of a piece of equipment (pipe, in this instance). The predicted asset performance then provides the basis for the application of other asset management tools, allowing the development of the ultimate maintenance or replacement strategies that optimize asset cost with any number of other factors, such as availability for service or risk avoidance.

Availability Workbench Software

Avista developed reliability forecasts for its Aldyl A and other piping using Availability Workbench™ software. This 'off the shelf software' was introduced by Isograph, Ltd., the world's leader in reliability analysis software. Availability Workbench was first introduced in 1988, and is used to support asset decision making in over 7,000 sites around the world and across a range of industries, including Aerospace, Automotive, Chemical, Defense, Electronics, Manufacturing, Mining, Oil and Gas, Power Generation, Railways, and Utilities. Avista's version of the model was released in 2009.

Reliability Forecasting

Availability Workbench has four modules, one of which, the Weibull module, is used to create reliability forecasts (curves) for an asset. Reliability curves for gas piping are generated from input data that include pipe inventory (type, brand, footage, location, soil conditions, etc.), current age of piping, historic and current failure information and repair data. Avista uses predominantly its own historical data for these inputs, but when they must be estimated, they are vetted by subject matter experts within the company. The model integrates pipe age and failure and repair data, and then by applying a conventional Weibull-curve mathematical model, it produces probability curves that represent the expected failure rates over time for each failure mode, such as the brittle-like cracking associated with Aldyl A services tapped to steel mains. The reliability curves represent how quickly the rest of the pipe is at risk of failing, shown as the percentage of failures expected each year over time.

Forecasting the Reliability of Aldyl A Piping

The objective of Avista's reliability modeling was to forecast expected failures for elements of Avista's Aldyl A piping system, compared with that of steel and latest-generation polyethylene pipe. The observed Aldyl A failure modes, discussed above, including leak data for other types of gas pipe in Avista's system, provided high-quality leak and age information for the reliability modeling. Forecasting was performed for the following pipe 'classes' in Avista's system.

a. Aldyl A Main pipe of Pre-1984 manufacture (Alathon 5040 and 5043 resins, including low ductile inner wall pipe)
b. Aldyl A Main pipe manufactured during 1984 and after (Alathon 5046-C and 5046-U resins)
c. Aldyl A Services Tapped to Steel Main (Bending Stress Services)
d. Steel pipe
e. Newer Polyethylene pipe (1990 and later)

To perform the modeling, the data for these pipe classes must be input as discrete elements, which are described as follows:

Main Pipe - Analyzed using 50-foot segments as discrete modeling elements.

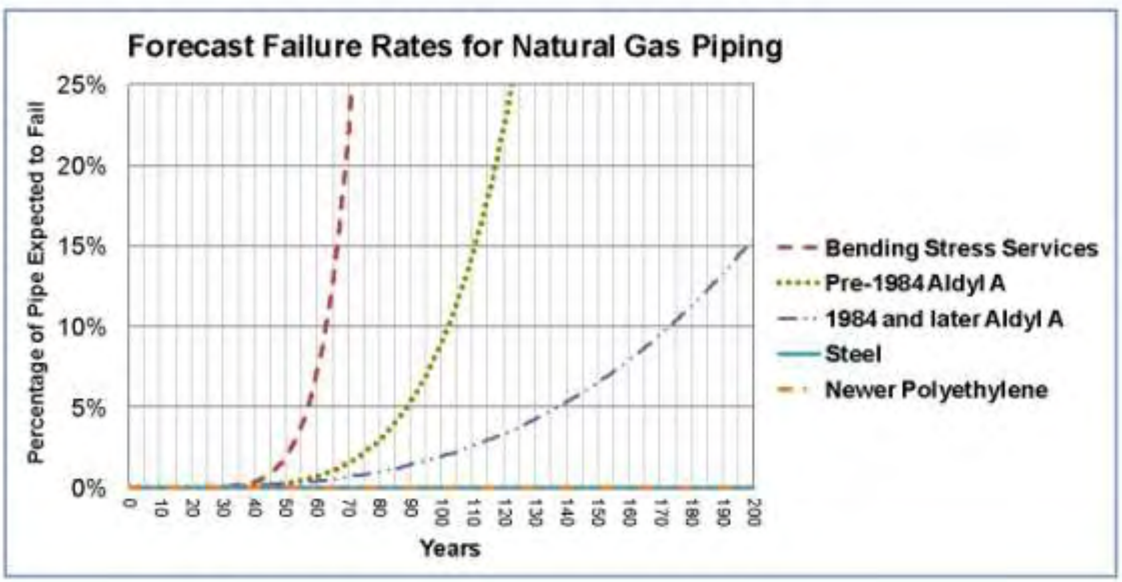
Services Tapped from Steel Mains - Avista identified 16,000 such services in its system, also referred to as 'bending stress tees.' For the reliability modeling, the individual service is the discrete element.

Forecasting Results

Forecast Piping Failures

Results of the forecast modeling, for the pipe classes evaluated, are represented as 'curves' showing the percentage of the amount of each pipe class that is projected to fail in each year of the forecast time period. The resulting reliability curves are shown in the graph below in Figure 5.

Figure 5. The expected failure rates for several classes of pipe in Avista's system, as forecast by Availability Workbench Modeling. The "Steel" curve is obscured by the "Newer Polyethylene" curve, both of which are essentially flat lines.



The failure curves show dramatic differences in the expected life for the pipe classes evaluated. The difference in expected life between the Aldyl A products as a group, compared with that of steel and newer-generation plastic pipe, is particularly evident. Striking also, are the expected performance differences among the classes of Aldyl A pipe evaluated, providing some clear trends useful in designing remediation strategies.

Dependability of Forecasting Future Failures

The reliability forecast is essentially a mathematical calculation of the 'chance' of future failure and decisions of significant risk and financial magnitude are based, at least in part, on that result. Importantly though, the forecast has a 'real numbers' foundation in the actual leak data, records of material failure and repair, and the relationship of those events with time. For Aldyl A pipe, the model is using observed endpoints in the life of the pipe resulting from a loss in ductility and slow crack growth, for example, and integrating that with other data to forecast future expected failures. Comparatively, the relatively rare observed failures in steel pipe and newer-generation plastic pipe are reflected in their nearly-flat cumulative failure curves. The value of using proven reliability forecasting approaches and widely-adopted software is derived from their ubiquitous application across reliability-critical industries, and their continuous testing, evaluation, and support. Finally, as Avista adds new data in coming years for pipe failures of all material classes, including Aldyl A, it serves to increase the statistical power of the forecast results.

Understanding the Significance of Cumulative Failure Curves

Although the failure curves for the different classes of pipe differ significantly over the long term, as mentioned, the failure rates also appear to remain below one percent for the first 45 years for Aldyl A services tapped to steel main, and for 65 years for Pre-1984 Aldyl A main pipe. Since the weighted average age for Aldyl A pipe in Avista's system is 32 years, it would appear that we might have ample time before the failure rate would start to rise substantially for Pre-1984 Aldyl A main pipe. Using the Pre-1984 main pipe in Washington as an example, the failure curve estimates that when this pipe is 65 years old that approximately one percent of it will fail in that single year. Given that Avista has 328 miles of this vintage pipe in Washington, that mileage equals nearly 35,000 discrete elements (50-ft sections) in the forecast model. The one percent failure, then, translates to 346 leaks in that 65th year. To put this failure rate into perspective, consider the 113 leaks documented (primarily on Pre-1984 main pipe) over the past five years in Washington state. The 113 leaks equal an average of 22.6 leaks per year, or an annual failure rate of 0.06 percent. Since it is expected that the number of hazardous leaks and incidents would increase proportionally with the increase in total leaks, then it's easy to imagine just how unacceptable the pipe performance would be at an annual failure rate of one percent.

Prudent Management of Anticipated Failures

To carry this point further, if we "zoom-in" on the curves we can gauge the significance of the change in failure rate that is expected ten years from today. At that point the weighted average age of Aldyl A pipe in Avista's system will be 42 years, and the expected failure rate for Pre-1984 Aldyl A main pipe in that year will be just over one-tenth of one percent (0.12%), or 42 leaks in that year. This failure rate, while still just a tiny fraction of the one percent rate used in the example above, represents almost a doubling of the average annual rate for the past five years (22.6), a time when two of the documented leaks resulted in injury and property incidents and dozens more were categorized as hazardous leaks[3], timely repaired. The critical point in this example is the understanding that failures in buried natural gas piping can be prudently managed only when they are occurring at very low rates. Otherwise new leaks in the system occur too frequently to be detected by even annual leak surveys of the entire system, resulting in an increase in the likelihood of hazardous leaks and the potential for harmful incidents.

Priority Aldyl A Piping

Every pipeline operator strives to install and maintain a safe, reliable and cost-effective system. While the goal is complete system integrity, it is impossible to avoid having any leaks, especially on large systems such as Avista's with over 12,000 miles of mains and several hundred thousand services. Regulators and the industry acknowledge this reality through the adoption of standardized leak-survey methodologies, and recognized pipe remediation practices.

While leaks are inherent on a system, there are circumstances where the expected failure rate of a particular pipe begins to rise compared with that of other piping and industry norms. We have demonstrated that such is the case for portions of the Aldyl A pipe in Avista's system, and accordingly, we have determined these classes to be at-risk of quickly approaching a level of reliability that is unacceptable and in need of proactive remediation. It's for this reason that Avista refers to these pipe classes as "Priority Aldyl A piping."

IX. Formulation of a Management Program for Priority Aldyl A Pipe

The timely application of Avista's Integrity Management approach to its recent and ongoing leak analysis and its reliability modeling results, including Dr. Palermo's review, and the experience gained in three priority pipe-replacement projects in 2011, has prompted Avista to formulate a protocol for systematically managing its Aldyl A pipe. The following categories are useful classifications for Avista's definition of "priority Aldyl A pipe"[4]:

1. Aldyl A gas services tapped to steel main pipe
2. Pre-1973 Aldyl A main pipe
3. Pre-1984 Aldyl A main pipe

Avista has determined these classes of pipe are at risk of approaching unacceptable levels of reliability without prompt attention. Accordingly, Avista believes the decision to formulate a management program for its priority Aldyl A pipe is both timely and prudent,

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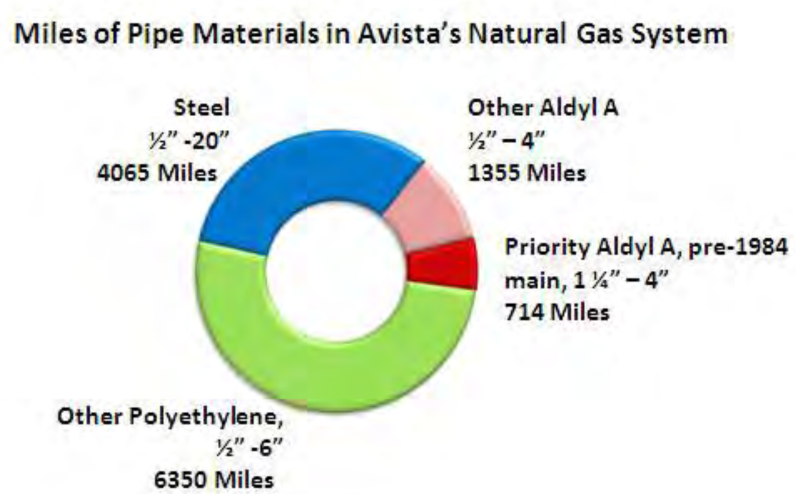
[3] The Pipeline and Hazardous Materials Safety Administration defines a "hazardous leak" as an unintentional release of gas that represents an existing or probable hazard to persons or property and requires immediate repair or continuous action until the conditions are no longer hazardous.
[4] Each class noted above is subject to material failures due to concentrated stresses such as rock impingement, bending stresses, squeeze off, and failures of service towers and caps.

and is consistent with results of our leak investigations, Integrity Management principles and the recent Call to Action of Secretary LaHood. The decision is also consistent with the prior federal bulletins on this subject and with the decisions of other similarly-situated utilities that have implemented similar pipe-replacement programs. Finally, given the significant amounts of priority Aldyl A pipe on Avista's system, commencing a protocol now provides us greater opportunity to manage these facilities in a prudent and cost-effective manner.

Priority Aldyl A Piping in Avista's System

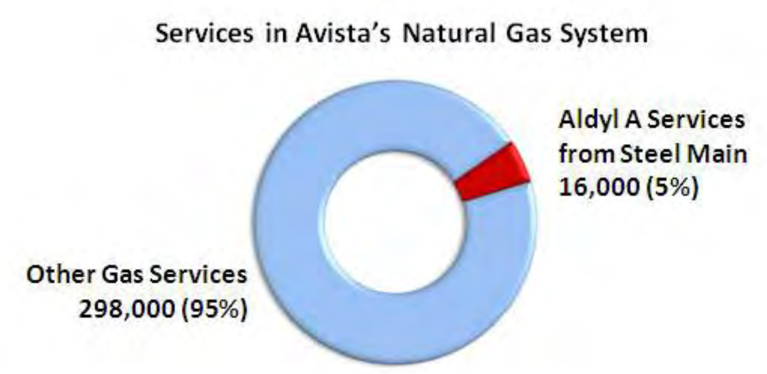
Main Pipe - Avista has approximately 12,500 miles of natural gas main pipe in its service territories in the States of Washington, Oregon and Idaho. Approximately seventeen percent of this total, or 2,000 miles, is Aldyl A pipe of all classes and sizes. Proportions of various classes of piping in Avista's system, including priority Aldyl A pipe (pre-1973 and pre-1984 mains) is shown below in Figure 6.

Figure 6. Avista's priority Aldyl A pipe, shown as a proportion of the different pipe classes in Avista's natural gas system (items 2 and 3 from the list above).



Gas Services - Avista has approximately 314,000 natural gas services, of which approximately 16,000, or five percent, are Aldyl service pipe tapped to steel main pipe, shown below in Figure 7 as priority Aldyl A services.

Figure 7. Avista's priority Aldyl A gas services (tapped from steel mains), shown as a proportion of Avista's total gas services.



X. Other Aldyl A Pipe Replacement Programs

Aldyl A Pipe in the Pacific Northwest

Through general conversation with our colleagues in western gas utilities, Avista believes it has a substantially greater proportion of Aldyl A pipe in its system than do our neighboring Pacific Northwest gas utilities. The proportions of Aldyl A in Avista's system (or of any other brand of early polyethylene pipe), however, is not a reflection of the unique purchasing practices of Avista, since plastic pipe quickly became the standard of the industry and the predominant pipe installed by utilities across the county. However, the proportions of early plastic pipe in a system do tend to track with the amount of system growth that gas utilities experienced during the 1970s and early 1980s. For Avista, this was a time of particularly rapid expansion of its natural gas system (from the Spokane metro area to outlying communities in its Washington and Idaho service territories), and consequently, the proportion of early Aldyl A pipe in our system reflects this period of expansion.

Established and Emerging Programs for Aldyl A Pipe Replacement

Two western utilities, Southwest Gas and Pacific Gas & Electric, have significant Aldyl A pipe management programs either well underway or anticipated, which are very briefly summarized below.

Southwest Gas – Responding to a fatality incident in the early 1990s, Southwest Gas entered into a settlement agreement with the Corporation Commission of Arizona to conduct additional leak monitoring and pipeline remediation (See Attachment 9). By the late 1990s, Southwest Gas had replaced 74 miles of Aldyl HD (high density) main pipe covered by the agreement, and had replaced another 648 miles of Aldyl A pipe based on its leak survey monitoring results. In 2005, Southwest Gas had another injury and property incident on their system involving Aldyl A pipe, and implemented an additional pipe replacement program in the vicinity of the incident. Southwest Gas has also worked closely with staff of the Public Utilities Commission of Nevada in the monitoring and replacement of what the Commission refers to as "aging" and "high risk" natural gas pipe, including Aldyl A pipe (See Attachment 10).

Pacific Gas & Electric - After some very high-profile natural gas incidents in 2011 that involved Aldyl A piping, Pacific Gas & Electric has announced plans to replace all the Pre-1973 Aldyl A pipe in its system (See Attachment 11). The utility reportedly has 7,907 miles of Aldyl A pipe of all classes in its system, which is about 19 percent of its gas system inventory. By comparison, Avista's Aldyl A pipe stock is about 16 percent of its system. Pacific Gas & Electric's planned replacement of its Pre-1973 Aldyl A pipe represents a massive effort because the utility plans to remove and replace the 1,231 miles of pipe in a proposed timeframe reported as in the range of three years, and at a cost said to exceed $1 billion, but that has not yet been formalized. There is some question regarding the selection of only pre-1973 Aldyl A for replacement in PG&E's system, since at least one recent high-profile incident was reported on newer vintage (still pre-1984) Aldyl A.

Developments of Interest

US Congresswoman Jackie Speier of California has been raising the awareness of Congress and Transportation Secretary, LaHood, in two separate actions. First, in May 2011, Speier sponsored House Resolution 22 entitled the "Pipeline Safety and Community Empowerment Act of 2011." The legislation provided for citizens being able to easily access pipeline maps and safety-related information from pipeline owners, prescribed certain changes in pipeline monitoring requirements, and called for the addition of physical safety devices to existing pipelines. The bill is currently under consideration by the House Committees on Transportation and Infrastructure, and Energy and Commerce.

In October 2011, Speier wrote to Secretary LaHood calling on him to direct the Pipeline and Hazardous Materials Safety Administration to "take immediate action to address the long-known safety risks associated with pre-1973 Aldyl-A plastic pipe manufactured by DuPont." She went on to advocate for the removal of this pipe from use in the U.S., and to commend Pacific Gas & Electric for its planned removal of all of its pre-1973 Aldyl A pipe. Citing the DuPont letters to customers, federal safety bulletins, and the Waterloo incident, she chided Congress for not taking action, and urged the Secretary to immediately do so (See Attachment 12).

XI. Designing Avista's Replacement Protocol for its Priority Aldyl A Pipe

Avista modeled two different approaches to the replacement program, one that was systematic, based on an established timeframe and one that was responsive to problem areas as they were identified.

Systematic Replacement Program

Time Horizon

Determining the appropriate length of time over which to replace the Priority Aldyl A pipe involves the optimization of several factors, including: 1) the overall urgency from a reliability and safety perspective, both present and forecast; 2) potential consequences; 3) the impact of more intensive leak survey methods to better identify priority facilities in need of replacement and in helping reduce the potential for harmful incidents; 4) the ability to effectively prioritize specific projects to better ensure facilities in greatest need are addressed earliest; 5) the availability of equipment and labor resources needed to conduct the work, and the ability to coordinate the work with Avista's ongoing construction programs; 6) program efficiency, and 7) the degree of rate pressure placed on customers, both in absolute terms and in relation to other reliability and safety investments required across the natural gas and electric business. Ultimately, Avista must ensure that management and removal of its Aldyl A pipe is conducted in a way that shields our customers from imprudent risk, while at the same protecting them from the burden of unnecessary costs.

Prudent Management of Potential Risk

Avista believes it is important to establish for our customers and other stakeholders that while there can never be 'zero risk' associated with the program, the potential risk can be prudently managed. On one hand, a replacement program carried out over a very short timeframe cannot prevent the occurrence of all leaks forecast to occur over the course of the program. But at the other extreme, it's clear that setting a replacement timeline that's too lengthy would likely result in safety, reliability and financial consequences for our customers and our business that could be regarded as unacceptable. Avista believes the timeline for the replacement program should optimize the factors mentioned above in a way that reduces the risk associated with Aldyl A pipe to the range of 'prudent risks' associated with the myriad other electric and gas facilities and practices that are used to serve the energy needs of utility customers. Avista's treatment of its Aldyl A pipe will be managed to comport with these sound business practices.

Prioritizing the Work

As important as the replacement timeline in prudently managing the reliability of Avista's Aldyl A piping, is the ability of the Asset Management and Distribution Integrity Management staff to partner in effectively prioritizing the pipe-replacement activities in a way that minimizes the potential for hazardous leaks. Results of the Availability Workbench modeling provide some support in prioritization but do not take into account factors such as soil conditions or the proximity to buildings or people. Obviously, a leak occurring in a vacant field will have little, if any, consequence and will likely be detected and repaired during the next leak survey. By contrast, the potential hazard of a leak increases with its proximity to people and structures, so replacing pipe that has a high probability of leaking and is located in populated areas is first priority.

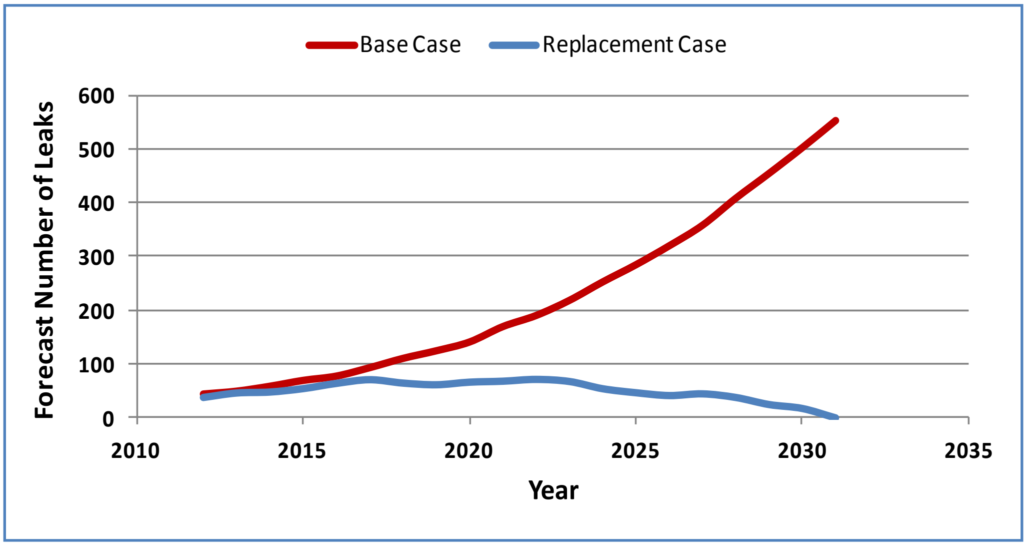
Avista's Integrity Management approach provides the analytical tools that integrate key knowledge and information needed to effectively prioritize replacement activities based on the potential hazard. In the prioritization process, each segment of Aldyl A pipe in Avista's system is assigned a relative risk ranking, based on its age, material, soil conditions, construction methods, and its maintenance history. This information is then loaded into Avista's GIS database containing the gas system maps. These maps contain a "layer" of grid squares (50 feet per side) that correspond with sections of the Aldyl A pipe. Each square is known as a "raster" and each raster contains all of the risk-related information that was loaded into the GIS system, as associated with the Aldyl A pipe at that precise geographic location.

Next, the software integrates the historic leak information for Aldyl A pipe on Avista's system with the risk data associated with each of the Aldyl A pipe segments, and predicts the geographic areas (via the risk rasters) where Aldyl A pipe failures are expected to be greatest. In the last step, the software integrates the results for expected failures with information for each risk raster that identifies the potential consequence of a leak on that segment (i.e. the proximity of that raster to buildings and people, and the population density/sensitivity of those structures). The end result is a color-coding of the rasters that provides a visual picture of where on the gas system that both the potential likelihood of a leak, and the potential consequence of a leak, are greatest. This approach provides Avista with a comprehensive and objective means of identifying Aldyl A pipe that has the highest priority for replacement.

Twenty-Year Proposal

Avista modeled various time horizons for the replacement program, up to a timeline of 30 years, and determined a replacement horizon in the range of twenty years to represent an optimum timeframe for removing and replacing its priority Aldyl A pipe. Shortening the timeline was found to have increasing cost impacts to customers but with little improvement in the numbers of expected facility failures. Lengthening the timeline past twenty years, however, was found to result in a substantial increase in the number of material failures expected. A replacement timeline of 25 years, for example, resulted in more than a doubling of the number of leaks expected when compared with the twenty year horizon. Under the twenty year replacement program, the number of material failures each year is expected to increase slightly until 2017, at which time the cumulative effect of priority piping replaced since 2012 begins to check the failure count and then drive it toward zero over the remaining course of the program (Figure 8).

Figure 8. Expected numbers of material failures in Avista's priority Aldyl A piping in two cases: Replacement Case - piping replaced over a twenty year horizon in the manner proposed by Avista in this report, and Base Case – assumed that priority piping was not remediated under any program.



Importantly, Avista is not suggesting that experiencing an increase in leaks on our system is "acceptable" per se, in particular, after having had two harmful incidents in the past few years. What we are saying, however, is that by using the Integrity Management model to prioritize work activities in the manner described above, Avista believes it can manage the forecast Aldyl A leaks in a way that significantly reduces their potential occurrence in areas that could result in harm. Under this approach, Avista believes it can prudently manage the replacement of priority Aldyl A pipe with the goal to avoid harmful incidents, and at a reasonable rate impact for our customers.

Initial Optimization

Importantly, Avista's proposal for a 20-year replacement program represents an optimization based on the information we have available today. Any number of factors could change as the work proceeds over the first few years that could result in a 'new' optimum time horizon. Avista will be collecting new leak survey and other information each year, and will continue to use its Asset Management models to further refine expected trends and potential consequences, making program adjustments as appropriate.

Responsive Replacement Program

Avista also modeled a very-different pipe replacement strategy to provide a further measure of the efficacy of the systematic replacement program. This scenario, referred to as the Responsive Case, was essentially a reactive approach where pipe remediation and replacement activities would be driven by leak survey results and the magnitude of leak consequences. Under this case, it's expected that pipe replacement activity would commence at a lower level than in the systematic case, but would also vary significantly from year to year, depending on patterns of detected leaks and their consequences. Ultimately, however, the expected activity and spending levels would far exceed both the annual and cumulative costs of the systematic approach. This is because pipe segments are not replaced ahead of actual material failure (as happens in the structured case) and so the resulting work activity more generally follows the geometrically-increasing numbers of material failures expected over time. This scenario was easily judged as failing to provide an appropriate measure of prudence, including system safety, reliability, cost-efficiency, or business risk. Without a prioritized replacement protocol in place, Avista would be resigned to replacing pipe in response to serious leaks and potential incidents, after-the-fact, rather than with foresight.

From a practical standpoint, Avista believes that by managing the replacement of its priority Aldyl A pipe in a systematic way it can prudently manage potential risks and impacts to its customers and other stakeholders, plan for and use construction resources most efficiently, and plan more effectively for the capital and expense requirements necessary for the effort. This is clearly the case when compared with a responsive approach.

Dr. Palermo's Assessment of the Proposed Protocol for Managing Avista's Priority Aldyl A Piping

Following Avista's Integrity Management evaluations of failure trends in its Aldyl A piping, and the development of its proposed protocol, we invited Dr. Palermo to review the completed protocol and to judge, from his expert perspective, the overall effectiveness and adequacy of the program. Dr. Palermo completed his review in February 2012, and judged Avista's protocol to be highly responsive and appropriate to the management needs of the priority Aldyl A pipe in Avista's system. In particular, he noted his support for Avista's priority focus on pre-1973 Aldyl A pipe, and on the plan to remove and replace its pre-1984 Aldyl A mains. He further noted his agreement with Avista's priority for remediating Aldyl A services tapped to steel main pipe, and to the protocol of "managing in place" existing Aldyl A service piping between the mains and meters. Finally, Dr. Palermo agreed with the proposed twenty-year replacement time horizon for Avista's priority Aldyl A pipe, noting the reliability modeling results, and the effectiveness of Avista's increased leak survey and application of Integrity Management information, tools and analysis in prioritizing pipe replacement activities. Dr. Palermo reviewed and approved this affirmation prior to the finalization of this report.

XII. Application of Avista's Washington State Study Results to Aldyl A Pipe in the States of Oregon and Idaho

Forty-six percent of Avista's Aldyl A main pipe is currently in service in the State of Washington, and coincidentally, so are 46% of Avista's Aldyl A services tapped to steel mains. Since Avista's leak survey study and subsequent modeling results are based on Washington State data, then it follows that the expected results are most applicable to this jurisdiction. The degree to which the reliability modeling results are applicable to Avista's Aldyl A pipe in the States of Oregon and Idaho depend on factors such as the age of the at-risk pipe and on the known similarity of conditions under which the pipe was installed, including method (trenching or plowing), backfill material, compaction and squeeze-off practices, soil conditions and ambient soil temperature, etc. Avista is aware of at least some general differences among state jurisdictions, including more favorable soil conditions in Oregon, newer pipe materials, and construction techniques potentially more favorable to low-ductility pipe. A contributing complication, too, is the relatively large amount of pipe of unknown age and material in service in Oregon. This territory was acquired by Avista from a utility that did not have a consistent practice of mapping services, and some existing maps were lost before the purchase. As a result, Avista is conservatively managing this pipe as if it was priority Aldyl A pipe, until the time that these segments are verified by records review and possible field verification.

Most important to this discussion, however, is the fact that Avista is using its Integrity Management model to integrate leak survey and other data to develop the priority pipe replacement activities for each year of the program. Since comparable leak survey data from priority Aldyl A pipe in Idaho and Oregon will be included in the prioritization analysis, then regardless of any differences that do affect the expected reliability of the Aldyl A pipe, that inherent reliability will be automatically integrated into the modeling, ensuring that Avista is systematically replacing the pipe at greatest risk, regardless of the jurisdiction. Finally, since the Medford and Grants Pass, Oregon, service territory offers a 12-month construction season, Avista will be able to continuously mitigate priority Aldyl A piping within that area when northern territories are effectively unable to continue working.

XIII. Resource Requirements and Expected Cost

Staffing

Avista's proposed Aldyl A pipe replacement project represents a major undertaking, even when spread over a twenty-year horizon. In addition to the scope of the effort, there's added complexity in efficiently managing the project, since Avista's territory extends from Bonners Ferry, Idaho to Ashland, Oregon, a distance of over 650 miles. Each year, the deployment of equipment and inspection and construction personnel will have to be adjusted across this service area in response to the sites identified for highest-priority pipe replacement in any given year. Avista is planning to coordinate with contractors to manage much of this construction, and since this project represents a long-term construction commitment, it is expected that the pool of contractors bidding for this work will be substantial, resulting in advantageous pricing and flexibility of field labor.

Though much of the physical construction will be accomplished through the use of contractors, there will still be a need to increase Avista's internal staffing to manage the flow of information, quality assurance, mapping, and related project documentation. Quality assurance is a critical project element that Avista will rigorously control. Effective remediation of Avista's priority Aldyl A pipe is a critically-important corporate objective, and we must continually ensure that sound inspection, training and auditing delivers the results we expect. Finally, the pipe replacement activities themselves will often have disruptive effects on our customers and others. Avista will carefully coordinate customer and community communications and notifications in an effort to minimize the effects of any disruptions.

Capital Costs

Avista's analysis and planning effort is projecting capital costs just over $10 million annually from the year 2013 – 2032. Actual costs will vary somewhat depending on the prioritization of piping to be replaced each year, among other factors, and the calculated amounts will also be subject to annual inflation. Avista is planning to spend approximately $5 million in capital on this program in 2012, and $8 million in 2013, allowing for effective planning with contractors, hiring Avista staff, and developing a solid project management foundation for years 2013 and beyond.

Proposed Protocol for Managing Select Aldyl A Pipe in Avista Utilities' Natural Gas System

Attachment 1

1982 DuPont Letter

1982 DuPont Letter

11/04/2003 17:18 FAX 9184469369 UPONOR ALDYL CO 005

Z-189 REV. 4/81

ESTABLISHED 1802

E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED
WILMINGTON, DELAWARE 19898

POLYMER PRODUCTS DEPARTMENT

December 17, 1982

It has now been over 18 years since Du Pont developed and introduced the first complete polyethylene piping system designed specifically to meet the needs of the gas distribution industry. Over this period of time, the use of Du Pont's Aldyl® "A" piping system and other polyethylene systems has increased to the point that 84% of the gas distribution pipe installed in 1981 was polyethylene. The outstanding overall performance of the polyethylene pipe installed since 1964 is the primary reason that polyethylene pipe has become the standard for the industry. We believe that the value of polyethylene piping systems has been well documented.

As a responsible long-term supplier committed to the gas industry, we have had a continuing research program aimed at defining the ultimate service life and failure modes of polyethylene pipe in gas distribution service. This program has been and is being supplemented by information received from gas utilities on their experience with Aldyl® "A" pipe.

In metal pipe, corrosion has been the ultimate failure mechanism that has determined when pipe should be replaced. So far, nearly all failures reported in polyethylene piping systems have been caused by either third-party damage or improper fusion practices during installation. These problems can and generally have been minimized by more extensive education and training programs. Although these causes may continue to be the primary reasons for leaks, we believe that every utility with polyethylene piping systems should maintain well-defined leak analysis procedures. Documentation and analysis of individual leak occurrences should help to define the ultimate failure mechanisms, the expected useful life, and appropriate repair or replacement programs.

As in the past, we will continue to assist our customers in planning details of their leak analysis programs including record-keeping, test methods, etc. As an example of the new information such programs can provide, two of our customers have reported instances* of leaks due to slits in Aldyl® "A" pipe made before 1973. The slits have only occurred in 1-1/4" and larger sized pipe. Nearly all of the slits were in pipe installed in point contact with rocks. This low frequency of leaks due to slits has not been reported for pipe made after 1972. Our records indicate that a process improvement was made in late 1971 and early 1972 as part of our continuing effort to utilize our most up-to-date technology. We believe, therefore, that Aldyl® "A" pipe made since that time is more resistant to the formation of slits from point contact with rocks. However, as with coated steel pipe, polyethylene pipe should be installed using established methods which avoid point loading with rocks.

After finding these leaks, the two utilities have increased the frequency of their leak detection surveys for pipe installed before 1973, particularly in those subdivisions where other leaks suggest that rocks may have been included as part of the backfill. We believe that all utilities with Aldyl® "A" pipe installed prior to 1973 should consider more frequent leak detection surveys. The attached sheet shows the purchases by year for your company prior to 1973.

In the future, as we learn of other significant field performance data on our product or develop our own laboratory data, we will share this information with you. High quality polyethylene systems have become an important part of the gas distribution business in providing good performance and safety at minimum costs for installation and repair. It is important as the amount of pipe grows and service times increase, that the management of system maintenance proceeds on a rational, planned basis. We hope the ideas and information included here are helpful toward that end. We look forward to your comments and questions.

Sincerely,

Don F. Zerbe, Jr.
Marketing Manager
Aldyl® Piping Systems

DFZ:dmst
Attachment

* Averaging less than 1% of all field repairs.

Proposed Protocol for Managing Select Aldyl A Pipe in Avista Utilities' Natural Gas System

Attachment 2

1986 DuPont Letter

1986 DuPont Letter

11/04/2003 17:16 FAX 9184469369 UPONOR ALDYL CO 002

C 777-7

DU PONT ALDYL® PIPING SYSTEMS
QUALITY • INNOVATION • SERVICE

E. I. DU PONT DE NEMOURS & COMPANY (INC.) WILMINGTON, DELAWARE 19898
ALDYL® Piping Systems

August 25, 1986

Dear Customer:

Over twenty years have passed since the first full Aldyl® "A" Polyethylene Piping System was installed in gas distribution service. During those decades both the gas industry and system suppliers have gained experience. As a result, today's systems incorporate improved resins and protective additives, system components are readily available, tooling and installation techniques have been improved, and testing methods have been developed to define design strength and estimate long-term system performance.

Consistent with our position as a reliable and responsible supplier to the gas distribution industry, Du Pont has continued to conduct research programs aimed at new product development and better understanding of existing product performance. We have, over the past years, shared the results of this research effort with you, our customers.

One of the major technical advancements derived from these research programs has been the development by Du Pont of the Rate Process Method (RPM) to estimate long-term system performance. This accelerated test for estimating pressure capability at use conditions is based on the demonstrated Arrhenius principle, relating material strength to temperature. The method is supported by many hundreds of data points at several test temperatures.

RPM estimates enable us to quantify performance of Aldyl® "A" systems. These estimates have shown certain limitations in some 1-1/4 inch and larger Aldyl® pipe installed prior to 1973 which were not previously shown by standard state-of-the-art testing (ASTM D-2837) available at the time. RPM estimates have confirmed that service life of this pipe may be reduced by rock impingement, which is contrary to recommended practice, as communicated previously.

It has now also been shown that the life of pre-1973 1-1/4 inch and larger pipe is shortened at squeeze-off points. For example, RPM estimates show that for squeezed pre-1973 SDR-11 pipe operating at 60 psig and a ground temperature of 70°F (e.g. conditions in parts of the southwestern U.S.) a mean

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DU PONT

life of about 20 years, after squeeze, can be expected. When ground temperature is 60°F, however, the mean life of a squeeze point in such pipe is projected to be about 50 years. The effects of temperature, rock impingement and squeeze-off predicted by RPM are being substantiated by actual field experience.

Based on this new information, reinforcement is recommended to extend the life of pre-1973 pipe when squeeze-off procedures are used. Alternatively, through your own field experience you may have developed other methods you have found to be effective to extend life of squeezed polyethylene pipe.

There are a number of suppliers of reinforcement clamps, and an ASTM guide for selection and use of full encirclement type clamps is near completion. Key items of this proposed guide are summarized in the attachment.

RPM estimates show that for Du Pont's current Aldyl® "A" product:

- Resistance to failure as a result of rock impingement has been improved significantly; and
- Long-term performance is unaffected by squeeze-off (provided proper procedures are followed).

We trust this update on laboratory results and field experience will be helpful in managing Aldyl® systems. Our RPM data on squeeze-off, rock impingement, deflection and other conditions are available, should you wish to use them to help characterize your system, and we welcome discussion of these data with you. We look on such exchanges of information as part of our ongoing partnership in the safe, economical distribution of natural gas.

Sincerely,

E. J. Roddy
Manager
Aldyl® Piping Systems, U.S.
SPECIALTY PRODUCTS & SERVICES DIVISION

EJR1:04/dle
8/25/86
Attachment

SUMMARY OF PROPOSED ASTM DOCUMENT

STANDARD GUIDE FOR THE SELECTION AND USE OF FULL ENCIRCLEMENT TYPE BAND CLAMPS FOR REINFORCEMENT OR REPAIR OF POLYETHYLENE GAS PRESSURE PIPE

- Full encirclement band clamps can be used to reinforce PE pipe where it has been squeezed-off.
- The user should confirm that the band clamp manufacturer recommends his product for reinforcement of PE pipe.
- The user should obtain recommended step-by-step installation instructions from the band clamp manufacturer.
- General considerations to determine appropriateness of using band clamps, design requirements for band clamps, and test methods for evaluation are the responsibility of the band clamp manufacturer.
- The band clamp should be long enough so that it extends 2.5 inches beyond each side of the squeeze-off area.
- The PE pipe should be clean and rounded prior to band clamp installation.

This proposed ASTM document is on the current F-17 Main Committee ballot. Several wording changes may occur as the document proceeds through the ASTM ballot process. Since the proposed balloted document cannot be reproduced or quoted, the key items related to reinforcement of squeezed PE pipe have been summarized here. The final approved document may appear in the 1987 Book of ASTM Standards.

EJR1:04/dle
8/25/86

Proposed Protocol for Managing Select Aldyl A Pipe in Avista Utilities' Natural Gas System

Attachment 3

NTSB Special Investigation Report Brittle-Like Cracking in Plastic Pipe for Gas Service

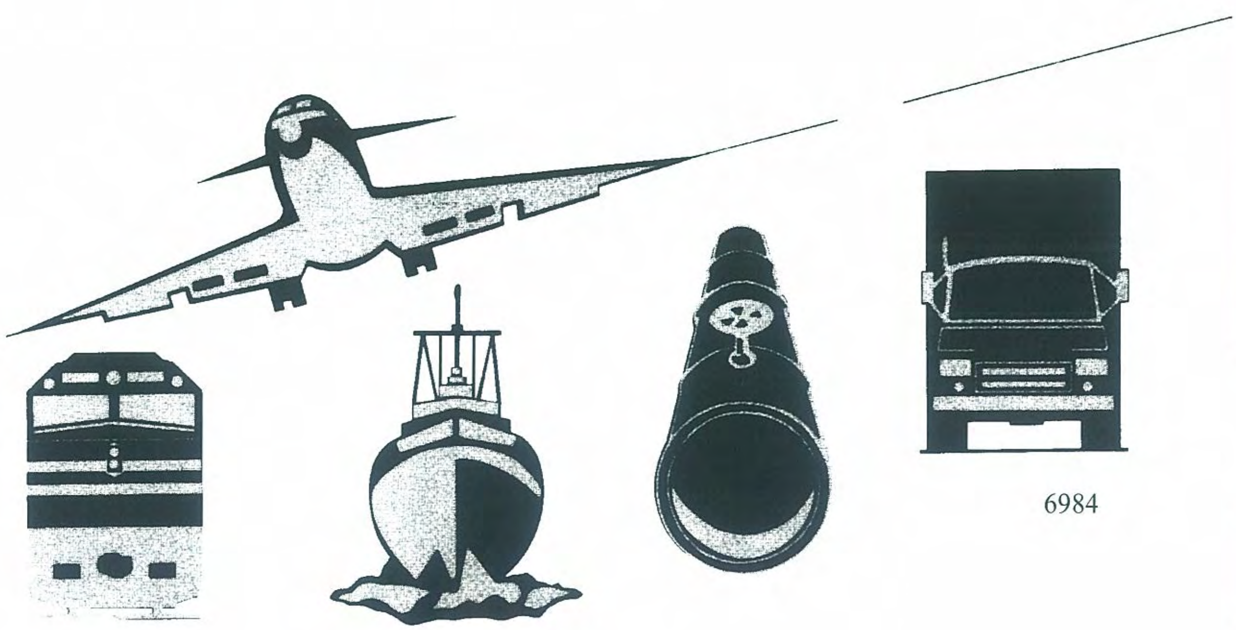
PB98-917001
NTSB/SIR-98/01

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

SPECIAL INVESTIGATION REPORT

BRITTLE-LIKE CRACKING IN PLASTIC PIPE FOR GAS SERVICE



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Abstract: Despite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel or other materials, the National Transportation Safety Board notes that a number of pipeline accidents it has investigated have involved plastic piping that cracked in a brittle-like manner. This special investigation report concludes that the procedure used in the United States to rate the strength of plastic pipe may have overrated the strength and resistance to brittle-like cracking of much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s. As a result, much of this piping may be susceptible to premature brittle-like failures when subjected to stress intensification, and these failures represent a potential public safety hazard.

The safety issues discussed in this report are the vulnerability of plastic piping to premature failures due to brittle-like cracking; the adequacy of available guidance relating to the installation and protection of plastic piping connections to steel mains; and performance monitoring of plastic pipeline systems as a way of detecting unacceptable performance in piping systems.

As a result of this special investigation, the National Transportation Safety Board issued recommendations to the Research and Special Programs Administration, the Gas Research Institute, the Plastics Pipe Institute, the Gas Piping Technology Committee, the American Society for Testing and Materials, the American Gas Association, MidAmerican Energy Corporation, Continental Industries, Inc., Dresser Industries, Inc., Inner-Tite Corporation, and Mueller Company.

The National Transportation Safety Board is an independent Federal agency dedicated to promoting aviation, railroad, highway, marine, pipeline, and hazardous materials safety. Established in 1967, the agency is mandated by Congress through the Independent Safety Board Act of 1974 to investigate transportation accidents, determine the probable causes of the accidents, issue safety recommendations, study transportation safety issues, and evaluate the safety effectiveness of government agencies involved in transportation. The Safety Board makes public its actions and decisions through accident reports, safety studies, special investigation reports, safety recommendations, and statistical reviews.

Information about available publications may be obtained by contacting:

National Transportation Safety Board
Public Inquiries Section, RE-51
490 L'Enfant Plaza, S.W.
Washington, D.C. 20594
(202) 314-6551

Safety Board publications may be purchased, by individual copy or by subscription, from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161
(703) 605-6000

BRITTLE-LIKE CRACKING IN PLASTIC PIPE FOR GAS SERVICE

SPECIAL INVESTIGATION REPORT

Adopted: April 23, 1998
Notation 6984

NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D.C. 20594

CONTENTS

APPENDIXES

INTRODUCTION

The use of plastic piping to transport natural gas has grown steadily over the years because of the material's economy, outstanding corrosion resistance, light weight, and ease of installing and joining. According to the American Gas Association (A.G.A.),[1] the total miles of plastic piping in use in natural gas distribution systems in the United States grew from about 9,200 miles in 1965 to more than 45,800 miles in 1970. By 1982, this figure had grown to about 215,000 miles, of which more than 85 percent was polyethylene.[2] Data maintained by Office of Pipeline Safety (OPS), an office of the Research and Special Programs Administration (RSPA) within the U.S. Department of Transportation (DOT), indicate that, by the end of 1996, more than 500,000 miles of plastic piping had been installed. Plastic piping as a percentage of all gas distribution piping installed each year has also grown steadily, as illustrated in figure 1.

Despite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel or other materials, the Safety Board notes that a number of pipeline accidents it has investigated have involved plastic piping that cracked in a brittle-like manner.[3] (See table 1 for information on three recent accidents.) For example, on October 17, 1994, an explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property. Six persons died and seven were injured in the accident. The Safety Board investigation determined that natural gas had been released from a plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.

[1]See appendix B for brief descriptions of the organizations, associations, and agencies referenced in this report.

[2]Watts, J., "Plastic Pipe Maintains Lion's Share of Market," *Pipeline and Gas Journal*, December 1982, p. 19, and National Transportation Safety Board Special Study--*An Analysis of Accident Data from Plastic Pipe Natural Gas Distribution Systems* (NTSB/PSS-80/1).

[3]The body of the report will make clear the distinction between brittle-like and ductile fractures.

The Safety Board also investigated a gas explosion that resulted in 33 deaths and 69 injuries in San Juan, Puerto Rico, in November 1996.[4] The Safety Board's investigation determined that the explosion resulted from ignition of propane gas that had migrated under pressure from a failed plastic pipe. Stress intensification at a connection to a plastic fitting led to the formation of brittle-like cracks.

The Railroad Commission of Texas investigated a natural gas explosion and fire that resulted in one fatality in Lake Dallas, Texas, in August 1997.[5] A metal pipe pressing against a plastic pipe generated stress intensification that led to a brittle-like crack in the plastic pipe.

A Safety Board survey of the accident history of plastic piping suggested that the material may be susceptible to brittle-like cracking under conditions of stress intensification. No statistics exist that detail how much and from what years any plastic piping may already have been replaced; however, as noted above, hundreds of thousands of miles of plastic piping have been installed, with a significant amount of it having been installed prior to the mid-1980s. Any vulnerability of this material to premature failure could represent a serious potential hazard to public safety.

In an attempt to gauge the extent of brittle-like failures in plastic piping and to assess trends and causes, the Safety Board examined pipeline accident data compiled by RSPA. The examination revealed that the RSPA data are insufficient to serve as a basis for assessing the long-term performance of plastic pipe.

[4]National Transportation Safety Board Pipeline Accident Report--*San Juan Gas Company, Inc./Enron Corp., Propane Gas Explosion in San Juan, Puerto Rico, on November 21, 1996* (NTSB/PAR-97/01).

[5]Railroad Commission of Texas Accident Investigation No. 97-AI-055, October 31, 1997.

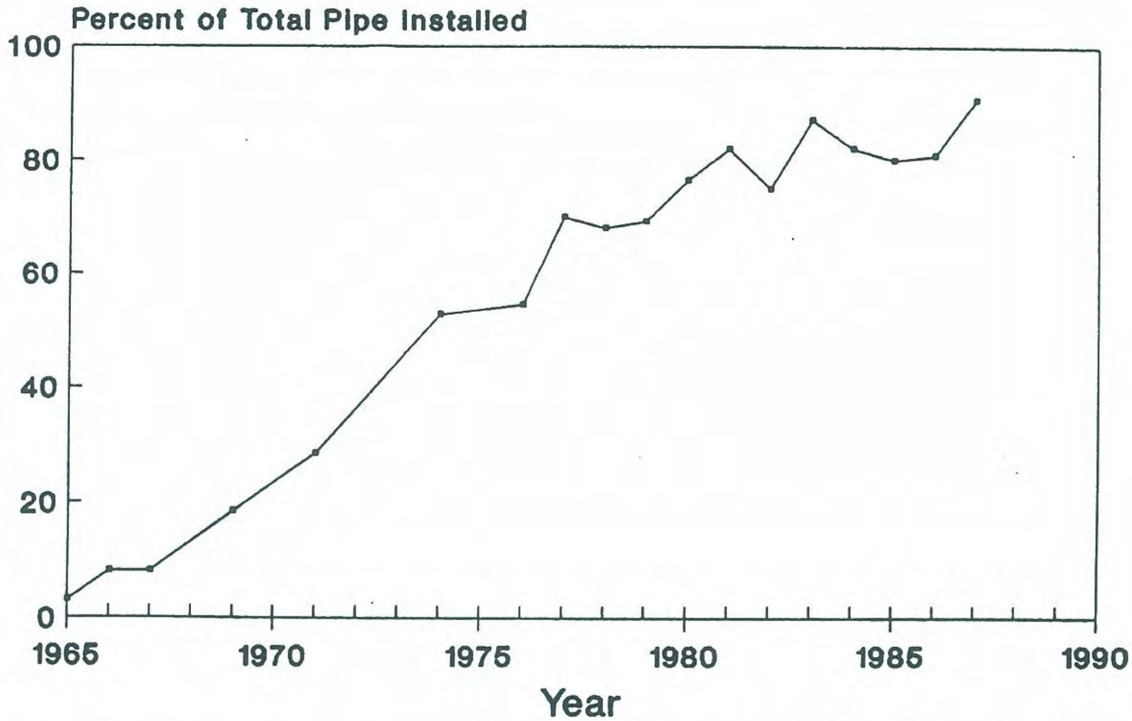

Figure 1 -- Plastic pipe as a percentage of all piping used in gas distribution. (*Source:* Duvall, D.E., "Polyethylene Pipe for Natural Gas Distribution," presented at the Transportation Safety Institute's Pipeline Failure Investigation course, 1997. Data from *Pipeline & Gas Journal* surveys.)

Lacking adequate data from RSPA, the Safety Board reviewed published technical literature and contacted more than 20 experts in gas distribution plastic piping to determine the estimated frequency of brittle-like cracks in plastic piping. The majority of the published literature and experts indicated that failure statistics would be expected to vary from one gas system operator to another based on factors such as brands and dates of manufacture of plastic piping in service, installation practices, and ground temperatures, but they indicated that brittle-like failures, as a nationwide average, may represent the second most frequent failure mode for older plastic piping, exceeded only by excavation damage.

The Safety Board asked several gas system operators about their direct experience with brittle-like cracks. Four major gas system operators reported that they had compiled failure statistics sufficient to estimate the extent of brittle-like failures. Three of those four said that brittle-like failures are the second most frequent failure mode in their plastic pipeline systems. One of these operators supplied data showing that it experienced at least 77 brittle-like failures in plastic piping in 1996 alone.

As an outgrowth of the Safety Board's investigations into the Waterloo, Iowa, San Juan, Puerto Rico, and other accidents, and in view of indications that some plastic piping, particularly older piping, may be subject to premature failure attributable to brittle-like cracking, the Safety Board undertook a special investigation of polyethylene gas service pipe. The investigation addressed the following safety issues:

- The vulnerability of plastic piping to premature failures due to brittle-like cracking;
- The adequacy of available guidance relating to the installation and protection of plastic piping connections to steel mains; and

Table 1 -- Recent pipeline accidents involving brittle-like cracking

Accident Location	Pipe Manufacturer	Year Pipe Manufactured	Year of Accident
Waterloo, Iowa	Amdevco/Century	1970	1994
San Juan, Puerto Rico	DuPont	1982	1996
Lake Dallas, Texas	Nipak	1970	1997

- Performance monitoring of plastic pipeline systems as a way of detecting unacceptable performance in piping systems.

As a result of its investigation, the Safety Board makes three safety recommendations to the Research and Special Programs Administration, one safety recommendation to the Gas Research Institute, three safety recommendations to the Plastics Pipe Institute, one safety recommendation to the Gas Piping Technology Committee, two safety recommendations to the American Society for Testing and Materials, one safety recommendation to the American Gas Association, two safety recommendations to MidAmerican Energy Corporation, two safety recommendations to Continental Industries, Inc., and one safety recommendation each to Dresser Industries, Inc., Inner-Tite Corporation, and Mueller Company.

INVESTIGATION

Accident History

On October 17, 1994, a natural gas explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property. Six persons died and seven were injured in the accident. The Safety Board investigation determined that the source of the gas was a 1/2-inch-diameter plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.[6]

Excavations following the accident uncovered, at a depth of about 3 feet, a 4-inch steel main. Welded to the top of the main was a steel tapping tee manufactured by Continental Industries, Inc. (Continental). Connected to the steel tee was a 1/2-inch plastic service pipe. (See figure 2.) Markings on the plastic pipe indicated that it was a medium-density polyethylene material manufactured on June 11, 1970, in accordance with American Society for Testing and Materials (ASTM) standard D2513. The pipe had been marketed by Century Utility Products, Inc. (Century). The plastic pipe was found cracked at the end of the tee's internal stiffener and beyond the coupling nut.

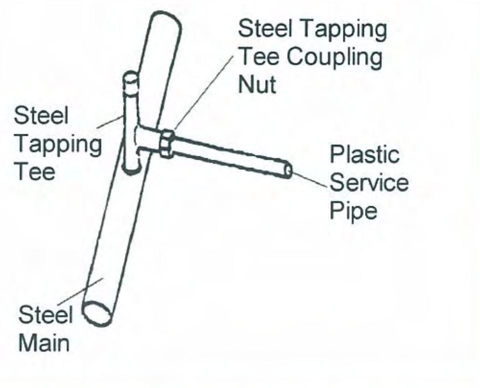

Figure 2 -- Typical plastic service pipe connection to steel gas main. Many connections are protected against shear and bending forces by a plastic sleeve that encloses the service pipe-to-tee connection on either side of the coupling nut.

The investigation determined that much of the top portion of the circumference of the pipe immediately outside the tee's internal stiffener displayed several brittle-like slow crack initiation and growth fracture sites. These slow crack fractures propagated on almost parallel planes slightly offset from each other through the wall of the pipe. As the slow cracks from different planes continued to grow and began to overlap one another, ductile tearing occurred between the planes. Substantial deformation was observed in part of the fracture; however, the initiating cracks were still classified as brittle-like.

Samples recovered from the plastic service line underwent several laboratory tests under the supervision of the Safety Board. Two of these tests were meant to roughly gauge the pipe's susceptibility to brittle-like cracking. These tests were a compressed ring environmental stress crack resistance (ESCR) test in accordance with ASTM F1248 and a notch tensile test known as a PENT test that is now ASTM F1473. Lower failure times in these tests indicate greater susceptibility to brittle-like cracking under test conditions. The ESCR testing of 10 samples from the pipe yielded a mean failure time of 1.5 hours, and the PENT testing of 2 samples yielded failure times of 0.6 and 0.7 hours. Test values this low have been associated with materials having poor performance histories[7]

[6]For more detailed information, see Pipeline Accident Brief in appendix A to this report.

[7]Uralil, F. S., et al., *The Development of Improved Plastic Piping Materials and Systems for Fuel Gas Distribution—Effects of Loads on the Structural and Fracture Behavior of Polyolefin Gas Piping*, Gas Research Institute Topical Report, 1/75 - 6/80, NTIS No. PB82-180654, GRI Report No. 80/0045, 1981, and Hulbert, L. E., Cassady, M. J., Leis, B. N., Skidmore, A., *Field Failure Reference Catalog for Polyethylene Gas Piping, Addendum No. 1*, Gas Research Institute Report No. 84/0235.2, 1989, and Brown, N. and Lu, X., "Controlling the Quality of PE Gas Piping Systems by Controlling the Quality of the Resin," *Proceedings Thirteenth International Plastic Fuel Gas Pipe Symposium*, pp. 327-338, American Gas

characterized by high leakage rates at points of stress intensification[8] due to crack initiation and slow crack growth typical of brittle-like cracking.

In late 1996, the Safety Board began an investigation of a November 1996 gas explosion that resulted in 33 deaths and 69 injuries in San Juan, Puerto Rico. The investigation determined that the explosion resulted from ignition of propane gas that, after migrating under pressure from a failed plastic pipe at a connection to a plastic fitting, had accumulated in the basement of a commercial building. The Safety Board concluded that apparent inadequate support under the piping and the resulting differential settlement generated long-term stress intensification that led to the formation of brittle-like circumferential cracks on the pipe.

The Railroad Commission of Texas investigation of a fatal natural gas explosion and fire in Lake Dallas, Texas, in August 1997 determined that a metal pipe pressing against a plastic pipe generated stress intensification that led to a brittle-like crack in the plastic pipe.

The Waterloo, San Juan, and Lake Dallas accidents were only three of the most recent in a series of accidents in which brittle-like cracks in plastic piping have been implicated. In Texas in 1971, natural gas migrated into a house from a brittle-like crack at the connection of a plastic service line to a plastic main.[9] The gas ignited and exploded, destroying the house and burning one person. The investigation determined that vertical loading over the connection generated long-term stress that led to the crack.

A 1973 natural gas explosion and fire in Maryland severely damaged a house, killed three occupants, and injured a fourth.[10] The Safety Board's investigation revealed that a brittle-like crack occurred in a plastic pipe as a result of an occluded particle that created a stress point.

The Safety Board's investigation of a natural gas explosion and fire that resulted in three fatalities in North Carolina in 1975[11] determined that the gas had accumulated because a concrete drain pipe resting on a plastic service pipe had precipitated two cracks in the plastic pipe. Available documentation suggests that these cracks were brittle-like.

A 1978 natural gas accident in Arizona destroyed 1 house, extensively damaged 2 others, partially damaged 11 other homes, and resulted in 1 fatality and 5 injuries.[12] Available documentation indicates that the gas line crack that caused the accident was brittle-like.

A 1978 accident in Nebraska involved the same brand of plastic piping as that involved in the Waterloo accident. A crack in a plastic piping fitting resulted in an explosion that injured one person, destroyed one house, and damaged three other houses.[13] The Safety Board determined that inadequate support under the plastic fitting resulted in long-term stress intensification that led to the formation of a circumferential crack in the fitting. Available documentation indicates that the crack was brittle-like.

A December 1981 natural gas explosion and fire in Arizona destroyed an apartment, damaged five other apartments in the same building, damaged nearby buildings, and injured three occupants.[14] The Safety Board's

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Association, Gas Research Institute, Battelle Columbus Laboratories, 1993.

[8]Stress intensification occurs when stress is higher in one area of a pipe than in those areas adjacent to it. Stress intensification can be generated by external forces or a change in the geometry of the pipe (such as at a connection to a fitting).

[9]National Transportation Safety Board Pipeline Accident Report--*Lone Star Gas Company, Fort Worth, Texas, October 4, 1971* (NTSB/PAR-72/5).

[10]National Transportation Safety Board Pipeline Accident Report--*Washington Gas Light Company, Bowie, Maryland, June 23, 1973* (NTSB/PAR-74/5).

[11]National Transportation Safety Board Pipeline Accident Brief--"Natural Gas Corporation, Kinston, North Carolina, September 29, 1975."

[12]National Transportation Safety Board Pipeline Accident Brief--"Arizona Public Service Company, Phoenix, Arizona, June 30, 1978."

[13]National Transportation Safety Board Pipeline Accident Brief--"Northwestern Public Service, Grand Island, Nebraska, August 28, 1978."

[14]National Transportation Safety Board Pipeline Accident Brief--"Southwest Gas Corporation, Tucson, Arizona, December 3, 1981."

investigation determined that assorted debris, rocks, and chunks of concrete in the excavation backfill generated stress intensification that resulted in a circumferential crack in a plastic pipe at a connection to a plastic fitting. Available documentation indicates that the crack was brittle-like.

A July 1982 natural gas explosion and fire in California destroyed a store and two residences, severely damaged nearby commercial and residential structures, and damaged automobiles.[15] The Safety Board's investigation identified a longitudinal crack in a plastic pipe as the source of the gas leak that led to the explosion. Available documentation indicates that the crack was brittle-like.

A September 1983 natural gas explosion in Minnesota involved the same brand of plastic piping as that involved in the Waterloo and Nebraska accidents.[16] The explosion destroyed one house and damaged several others, and injured five persons. The Safety Board's investigation determined that rock impingement generated stress intensification that resulted in a crack in a plastic pipe. Available documentation indicates that the crack was brittle-like.

One woman was killed and her 9-month-old daughter injured in a December 1983 natural gas explosion and fire in Texas.[17] The Safety Board's investigation determined that the source of the gas leak was a brittle-like crack that had resulted from damage to the plastic pipe during an earlier squeezing operation to control gas flow.[18]

A September 1984 natural gas explosion in Arizona resulted in five fatalities, seven injuries, and two destroyed apartments.[19] The Safety Board's investigation determined that a reaction between a segment of plastic pipe and some liquid trapped in the pipe weakened the pipe and led to a brittle-like crack.

During the course of the investigation of the accident at Waterloo, Iowa, the Safety Board learned of several other accidents, not investigated by the Safety Board, that involved cracks in the same brand of plastic piping as that involved in the Waterloo accident. Three of these accidents, which occurred in Illinois (1978 and 1979) and in Iowa (1983), resulted in five injuries and damage to buildings.[20] A 1995 accident in Michigan also involved a crack in this same brand of pipe.[21] Available documentation indicates that the cracks were brittle-like.

Strength Ratings, Ductility, and Material Standards for Plastic Piping

During the 1950s and early 1960s, when plastic piping was beginning to gain acceptance as an alternative to steel piping for the transport of water and gas, no established procedures existed for rating the strength of materials intended for use in plastic pressure piping.

In November 1958, the Thermoplastic Pipe Division of the Society of the Plastics Industry organized a group called the Working Stress Subcommittee.[22] The subcommittee, in January 1963, issued a procedure (hereinafter referred to as the PPI procedure) that specified a uniform protocol for rating the strength of materials used

[15]National Transportation Safety Board Pipeline Accident Brief--"Pacific Gas and Electric Company, San Andreas, California, July 8, 1982."

[16]National Transportation Safety Board Pipeline Accident Brief--"Northern States Power Company, Newport, Minnesota, September 19, 1983."

[17]National Transportation Safety Board Pipeline Accident Brief--"Lone Star Gas Company, Terell, Texas, December 9, 1983."

[18]Plastic pipe is sometimes squeezed to control the flow of gas. In some cases, squeezing plastic pipe can damage it and make it more susceptible to brittle-like cracking.

[19]National Transportation Safety Board Pipeline Accident Report--*Arizona Public Service Company Natural Gas Explosion and Fire, Phoenix, Arizona, September 25, 1984* (NTSB/PAR-85/01).

[20]Illinois Commerce Commission accident reports dated September 14, 1978, and December 4, 1979. Iowa State Commerce Commission accident report dated August 29, 1983.

[21]Research and Special Programs Administration Incident Report—"Gas Distribution System," Report No. 318063, January 8, 1996.

[22]This subcommittee was subsequently made into a permanent unit and was renamed the Hydrostatic Stress Board.

in the manufacture of thermoplastic pipe in the United States. In March 1963, the Thermoplastic Pipe Division adopted its current name, the Plastics Pipe Institute (PPI).

On July 1, 1963, the PPI established a voluntary program of listing the material strengths of plastic piping materials, specifically, those materials designed for water applications. To apply for a PPI listing, applicants sent strength test data to the PPI, often accompanied by the manufacturer's analysis of the data and a proposed material strength rating. The PPI would analyze the data and, if warranted, list the material for the calculated strength. The PPI did not certify or approve the material received or validate the data submitted, nor did it audit or inspect those submitting data.[23]

In simplified terms, the PPI procedure, which is performed by the materials manufacturers themselves, involves recording how much time it takes stressed pipe samples to rupture at a standardized temperature of 73 °F. The stresses used in the tests are recorded as "hoop stress," which is tensile stress in the wall of the pipe in a circumferential orientation (hence the term "hoop") due to internal pressure. Although hoop stress is expressed in pounds per square inch, it is a value quite different from the pipe's internal pressure.

The testing process involves subjecting pipe samples to various hoop stress levels, and then recording the time to rupture. For some samples at some pressures, rupture will occur in as little as 10 hours. As hoop stress is reduced, the time-to-failure increases. At some hoop stress level, at least one of the tested specimens will not rupture until at least 10,000 hours (slightly more than 1 year). After the rupture data points (hoop stresses and times-to-failure) for this material have been recorded, the data points are plotted on log-log coordinates as the relationship between hoop stress and time-to-failure. (See figure 3.) A mathematically developed "best-fit" straight line is correlated with the data points to represent the material's resistance to rupturing at various hoop stress levels.

Once the best-fit straight line is calculated to 10,000 hours, it is extrapolated to 100,000 hours (about 11 years). The hoop stress level that coincides with the point at which the line intersects the 100,000-hour time line represents the calculated long-term hydrostatic strength of that particular material.

To simplify the ratings and facilitate standardization, the PPI procedure grouped materials with similar long-term hydrostatic strength ranges into "hydrostatic design basis" categories. For example, those materials having long-term hydrostatic strengths between 1200 and 1520 psi were grouped together and assigned a hydrostatic design basis of 1250 psi. Those materials having long-term hydrostatic strengths between 1530 and 1910 psi were grouped together and assigned a hydrostatic design basis of 1600 psi.

To help ensure the validity of the mathematically derived line, the PPI procedure required the submission of all rupture data points. It further specified the minimum number of data points and minimum number of tested lots. The procedure employed statistical tests to verify the quality of data and quality of fit to the mathematically derived line. These measures excluded materials when the data demonstrated excessive data scatter due to either inadequate quality of data or deviation from straight line behavior through 10,000 hours.[24]

The PPI procedure, after some refinement, was issued as an ASTM method in 1969 (ASTM D2837). The PPI adopted a policy document[25] for PPI's listing service in 1968, which remained under PPI jurisdiction.

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[23]As a result of Safety Board inquiries to the PPI about its inability to verify the actual data submitted, the institute, in 1997, revised its policy document for its listing service to require a signed statement from applicants that data accompanying applications for a PPI listing are complete, accurate, and reliable.

[24]The PPI procedure also had restrictions on the degree of slope of the straight line so that the material's strength would not excessively diminish beyond 100,000 hours.

[25]Plastics Pipe Institute, *Policies and Procedures for Developing Recommended Hydrostatic Design Stresses for Thermostatic Pipe*, PPI-TR3-July 1968.

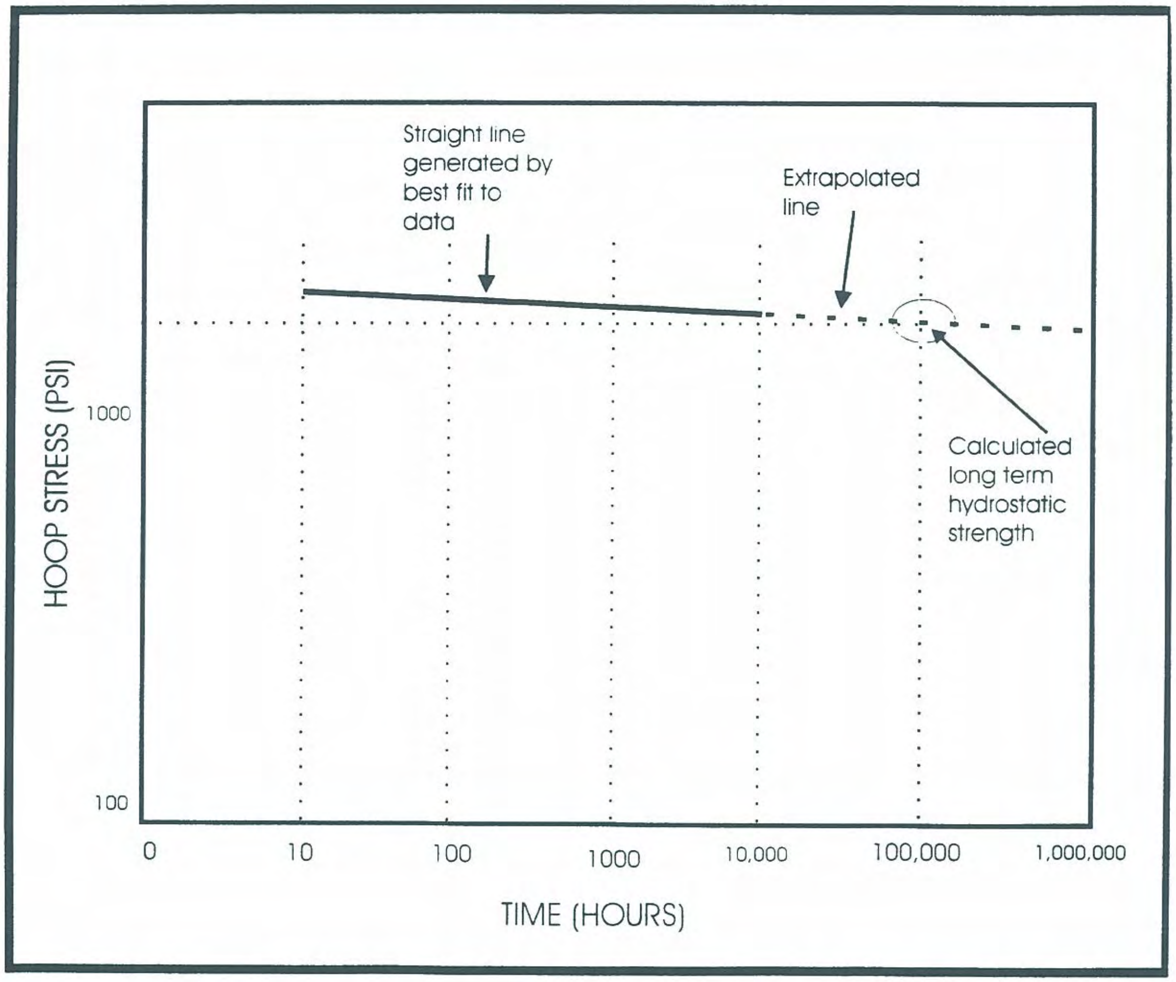

Figure 3 -- Stress rupture data plotted as best-fit straight line and extrapolated to determine long-term hydrostatic strength. (Derived from *A.G.A. Plastic Pipe Manual for Gas Service.)*

When polyethylene pipe fails during laboratory stress rupture testing at 73 °F, it fails primarily by means of ductile fractures, which are characterized by substantial visible deformation (see figure 4). During stress rupture tests, if hoop stress on the test piping is decreased, the time-to-failure increases, and the amount of deformation apparent in the failure decreases.[26] In pipe subjected to prolonged stress rupture testing, slit fractures[27] may begin to appear at some point (depending on the specific polyethylene resin material). Figure 5 shows a slit fracture that resulted from a stress rupture test. The PPI procedure did not differentiate between ductile and slit failure types, and, based on most available laboratory test data (at 73 °F),[28] assumed that both types of

[26]Mruk, S. A., "The Ductile Failure of Polyethylene Pipe," *SPE Journal*, Vol. 19, No. 1, January 1963.

[27]Because of the frequent lack of visible deformation associated with them, slit fractures are also referred to as brittle-like fractures.

[28]Kulhman, H. W., Wolter, F., Sowell, S., Smith, R. B., *Second Summary Report, The Development of Improved Plastic Pipe for Gas Service, Prepared for the American Gas Association*, Battelle Memorial Institute, covering the work from mid-1968 through 1969. Stress rupture tests were performed using methane and nitrogen as the internal pressure medium and air as the outside environment. Some experts have advised the Safety Board that stress rupture testing showing time-to-failure in the slit mode may vary with different pressure media and

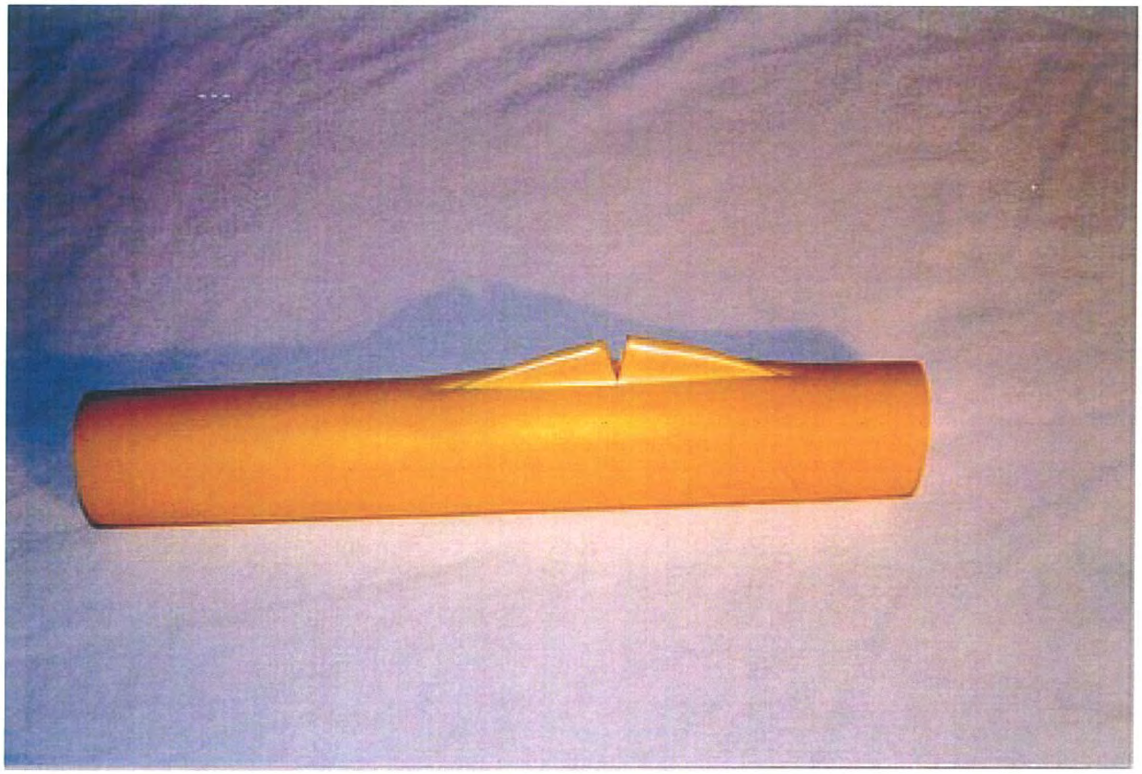

Figure 4 -- Ductile fracture resulting from stress rupture test. Note substantial deformation (ballooning) at the failure.

failures would be described by the same extrapolated (straight) line.

In 1963-64, the National Sanitation Foundation[29] amended its standard for plastic piping used for potable water service to require that manufacturers furnish evidence of having an appropriate strength rating in accordance with the PPI procedure. Manufacturers then decided to utilize the PPI listing service, having determined that this was the most convenient way to furnish the required evidence.

In 1966, the ASTM issued ASTM D2513, the society's first standard specification covering polyethylene plastic piping for gas service.[30] ASTM D2513 made reference to long-term hydrostatic strength and hydrostatic design stress and included an appendix defining these terms in accordance with the PPI procedure.[31] It also required that polyethylene pipe meet certain requirements of ASTM D2239 (a polyethylene pipe specification for water service), which also included references to the PPI procedure. ASTM D2513 did not explicitly require materials to have a PPI listing.

environments and that Battelle Memorial Institute's choices for these fluids may have contributed to the slow recognition in the United States of a downturn in the stress rupture line.

[29]Now known as NSF International.

[30]This standard also included plastic piping materials other than polyethylene.

[31]Although adherence to ASTM appendixes is not mandatory, the PPI procedure was the only industry-accepted mechanism to determine long-term hydrostatic strength and hydrostatic design stress.

Figure 5 -- Slit fracture resulting from a stress rupture test conducted at 100 °F. Note lack of deformation visible in the fracture. This pipe was manufactured by DuPont in 1977. After failing Minnegasco's incoming inspection tests, the pipe was subjected to stress rupture testing. (*Source:* Henrich, R.C., and Funck, D.L., "Effects of ESCR Variation on Some Other Properties of Plastic Pipe." *Proceedings, Eighth Annual Plastic Fuel Gas Pipe Symposium, 1983.)*

Even without an explicit requirement, some manufacturers voluntarily obtained PPI listings for their resin materials[32] intended for gas use, and some others,[33] as noted above, obtained PPI listings for their resins that were intended for water use (but were similar to their resins intended for gas service) as a way of meeting National Sanitation Foundation requirements.

In 1967, the United States of America Standards Institute B31.8 code,[34] *Gas Transmission and Distribution Piping Systems*, for the first time recognized the suitability of plastic piping for gas distribution service and included requirements for the pipings' use. The 1966 issuance of ASTM D2513 and the 1967 inclusion of plastic piping within B31.8 cleared the way for the general use of plastic piping for gas distribution.[35] B31.8 included a design equation (see discussion below), and although the code, like the ASTM standard, did not explicitly require a PPI listing, it did require that material used to manufacture plastic pipe establish its long-term hydrostatic strength in accordance with the PPI procedure.

[32]Resins are polymer materials used for the manufacture of plastics.

[33]For example, E. I. du Pont de Nemours & Company, Inc., and Union Carbide Corporation.

[34]Now known as ASME B31.8.

[35]*A.G.A. Plastic Pipe Handbook for Gas Service*, American Gas Association, Catalog No. X50967, April 1971.

On August 12, 1968, the Natural Gas Pipeline Safety Act was enacted, requiring the DOT to adopt minimum Federal regulations for gas pipelines. In December 1968, the DOT instituted interim Federal regulations by federalizing the State pipeline safety regulations that were in place at the time. The DOT, having concluded that the majority of the States required compliance with the 1968 version of B31.8, adopted that version of the code for the Federal regulations covering those States not yet having their own natural gas pipeline safety regulations.

Most of these Federal interim standards were replaced in November 1970 by 49 *Code of Federal Regulations* (CFR) 192; however, the interim provisions concerning the design, installation, construction, initial inspection, and initial testing of new pipelines remained in effect until March 1971. At that time, 49 CFR 192 incorporated the design equation for plastic pipe from B31.8 and also required that plastic piping conform to ASTM D2513.[36]

The 1967 version of B31.8 introduced fixed design factors[37] (subsequently incorporated into 49 CFR 192) as a catch-all mechanism to account for various influences on pipe performance and durability. These influences included external loadings, limitations of and imprecision in the PPI procedure, variations in pipe manufacturing, handling and storage effects, temperature fluctuations, and harsh environments.[38] A design equation was used to determine the allowable gas service pipe pressure rating based on the hydrostatic design basis category, pipe dimensions, and design factor.[39] The design basis for plastic pipe thus used internal pressures as a design criterion but did not directly take into account additional stresses that could be generated by external loadings, despite the fact that field failures in plastic piping systems were frequently associated with external loads but were rarely attributable to internal pressure effects alone.[40]

Kulmann and Mruk have reported that no direct basis was established to design for external loads because:

- The industry had no easy means of quantifying external loads and their effects on plastic piping systems;[41] and

- Many in the industry believed that plastic piping, like steel and copper piping, behaved as a ductile material that would withstand considerable deformation before undergoing damage, thus alleviating and redistributing local stress concentrations that would crack brittle materials such as cast iron. This belief resulted from short-term laboratory tests showing that plastic piping had enormous capacity to deform before rupturing.[42]

Because of plastic piping's expected ductile behavior, many manufacturers believed it safe to base their designs on average distributed stress concentrations generated primarily by internal pressure and, within reason, to neglect localized stress concentrations. They believed such stress would be reduced by localized yielding, or deformation. Mruk and Palermo have pointed out that design protocols were predicated on the assumption of such ductile behavior.[43]

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[36]RSPA reviews revised editions of ASTM D2513 for acceptability before referencing them in 49 CFR 192.

[37]A design factor is similar to a safety factor, except that a design factor attempts to account for other factors not directly included within the design equation that significantly affect the durability of the pipe.

[38]Reinhart, F. W., "Whence Cometh the 2.0 Design Factor," Plastics Pipe Institute, undated, and Mruk, S. A., "Validating the Hydrostatic Design Basis of PE Piping Materials."

[39]The design equation (with the current design factor, 0.32) can be found in 49 CFR 192.121, although 192.121 erroneously references the long-term hydrostatic strength instead of the hydrostatic design basis category. RSPA is currently conducting rulemaking activities to correct this error.

[40]Kulmann, H. W., Wolter, F., Sowell, S., "Investigation of Joint Performance of Plastic Pipe for Gas Service," *1970 Operating Section Proceedings*, American Gas Association, pp. D-191 to D-198.

[41]Kulmann, Wolter, and Sowell.

[42]Mruk, S. A., "Validating the Hydrostatic Design Basis of PE Piping Materials."

[43]Mruk, S. and Palermo, E., "The Notched Constant

Figure 6 -- Slit fracture on a polyethylene pipe manufactured by DuPont that was found leaking and removed from a gas piping system.

In contrast, cast iron piping has recognized brittle characteristics. The design basis for cast iron therefore does not assume that localized yielding or deformation will reduce stress intensification. As a result, the design protocol for cast iron includes the quantification and direct input of external loading factors that can generate localized stress intensification.[44]

Failures in polyethylene piping that occur under actual service conditions are frequently slit failures; ductile failures are rare.[45] Figure 6 shows a slit (brittle-like) fracture in a pipe that was found leaking and had to be replaced. A rock pressing against the plastic pipe generated long-term stress intensification that led to the formation of the brittle-like crack. Slit failures in polyethylene, whether occurring during stress rupture testing or under actual service conditions, result from crack initiation and slow crack growth and are similar to brittle cracks in other materials in that they can occur with little or no visible deformation.[46]

Tensile Load Test: A New Index of the Long Term Ductility of Polyethylene Piping Materials," summary of presentation given in the Technical Information Session hosted by ASTM Committee F17's task group on Project 62-95-02, held in conjunction with ASTM Committee F17's November 1996 meetings, New Orleans, LA.

[44]Mruk and Palermo and Hunt, W. J., "The Design of Grey and Ductile Cast Iron Pipe," *Cast Iron Pipe News*, March/April 1970.

[45]Mruk, S. A., "Validating the Hydrostatic Design Basis of PE Piping Materials," and Bragaw, C. G., "Fracture Modes in Medium-Density Polyethylene Gas Piping Systems," *Plastics and Rubber: Materials and Applications*, pp. 145-148, November 1979.

[46]Mruk and Palermo have quantified and discussed the deformation in brittle-like failures in: Mruk, S. and Palermo, E., "The Notched Constant Tensile Load Test: A New Index of the Long Term Ductility of Polyethylene

Figure 7 -- Interior of polyethylene pipe from San Juan pipeline accident showing brittle-like crack with no visible deformation.

Figure 7 illustrates brittle-like cracking that was found in a plastic pipe involved in the fatal propane gas explosion in San Juan, Puerto Rico, in November 1996. That pipe was manufactured in 1982 by E. I. du Pont de Nemours & Company, Inc., (DuPont) at its Pencador, Delaware, plant. Apparently, differential settlement resulting from inadequate support under the piping generated long-term stress intensification that led to the formation of brittle-like cracks in the pipe.

Figure 8 shows a brittle-like crack that was found in a plastic pipe involved in the fatal natural gas explosion and fire in Lake Dallas, Texas, in August 1997. That pipe was manufactured in 1970 by Nipak, Inc. A metal pipeline pressing against the plastic pipe generated long-term stress intensification that led to the crack.

During the 1960s and 1970s, some experts began to question the validity of the PPI procedure's assumption of a continuing, gradual straight-line decline in strength (figure 3). [47] By the late 1970s and early 1980s, the plastic piping industry in the United States realized that

Piping Materials," summary of presentation given in the Technical Information Session hosted by ASTM Committee F17's task group on Project 62-95-02, held in conjunction with ASTM Committee F17's November 1996 meetings, New Orleans, LA, and Mruk, S. A., "Validating the Hydrostatic Design Basis of PE Piping Materials," pp. 202-214, 1985.

[47]The 1971 *A.G.A. Plastic Handbook for Gas Service* noted that the cause and mechanisms of brittle fractures sometimes found with long-term stress rupture testing was not yet well established. Two of the pioneering papers in the United States to suggest a downturn in long-term hydrostatic strength with brittle-like failures or in elevated temperature testing were: Mruk, S. A., "The Ductile Failure of Polyethylene Pipe," *SPE Journal*, Vol. 19, No. 1, January 1963, and Davis, G. W., "What are Long Term Criteria for Evaluating Plastic Gas Pipe?" *Proceedings Third A.G.A. Plastic Pipe Symposium*, American Gas Association, pp. 28-35, 1971.

Figure 8 -- Brittle-like crack in pipe involved in August 1997 accident in Lake Dallas, Texas. The crack extends from the left to upper right of the area defined by the ellipse.

testing piping materials at elevated temperatures was a way to accelerate failure behavior that would occur much later at lower temperatures (such as 73 °F). Based on data derived from elevated-temperature testing, the industry concluded that the gradual straight-line decline in strength assumed by the PPI procedure was not valid. Instead, two distinct failure zones were indicated for polyethylene piping in stress rupture testing. (See figure 9.) The first zone is characterized by the gradual straight-line decline in strength accompanied primarily by ductile fractures. The first zone gradually transitions to the second zone, which is characterized by a more rapid decline in strength accompanied by brittle-like fractures only. The time and magnitude of this more rapid decline in strength varies by type and brand of polyethylene. Piping manufacturers have worked to improve their products' resistance to slit-type failures and thus to push this downturn further out in time. The PPI procedure did not account for this downturn, and the difference between the actual falloff shown in figure 9 and the projected straight-line strengths shown in figure 3 for listed materials became more pronounced as the lines were extrapolated beyond 100,000 hours.

As manufacturers steadily improved their formulations to delay the onset of the downturn in long-term strength and associated brittle-like behavior, PPI and ASTM industry standards were upgraded to reflect what the major manufacturers were able and willing to accomplish.[48] Accordingly, and because a consensus of manufacturers recognized the relationship between

[48]Both the PPI and the ASTM work on a consensus principle, meaning that requirements are put into place only when a consensus of voting members is reached. The PPI is a manufacturers' organization. With respect to the ASTM technical committee that generates requirements for plastic piping, the major piping manufacturers participate actively in the committee and are in a position to influence ASTM strength rating requirements.

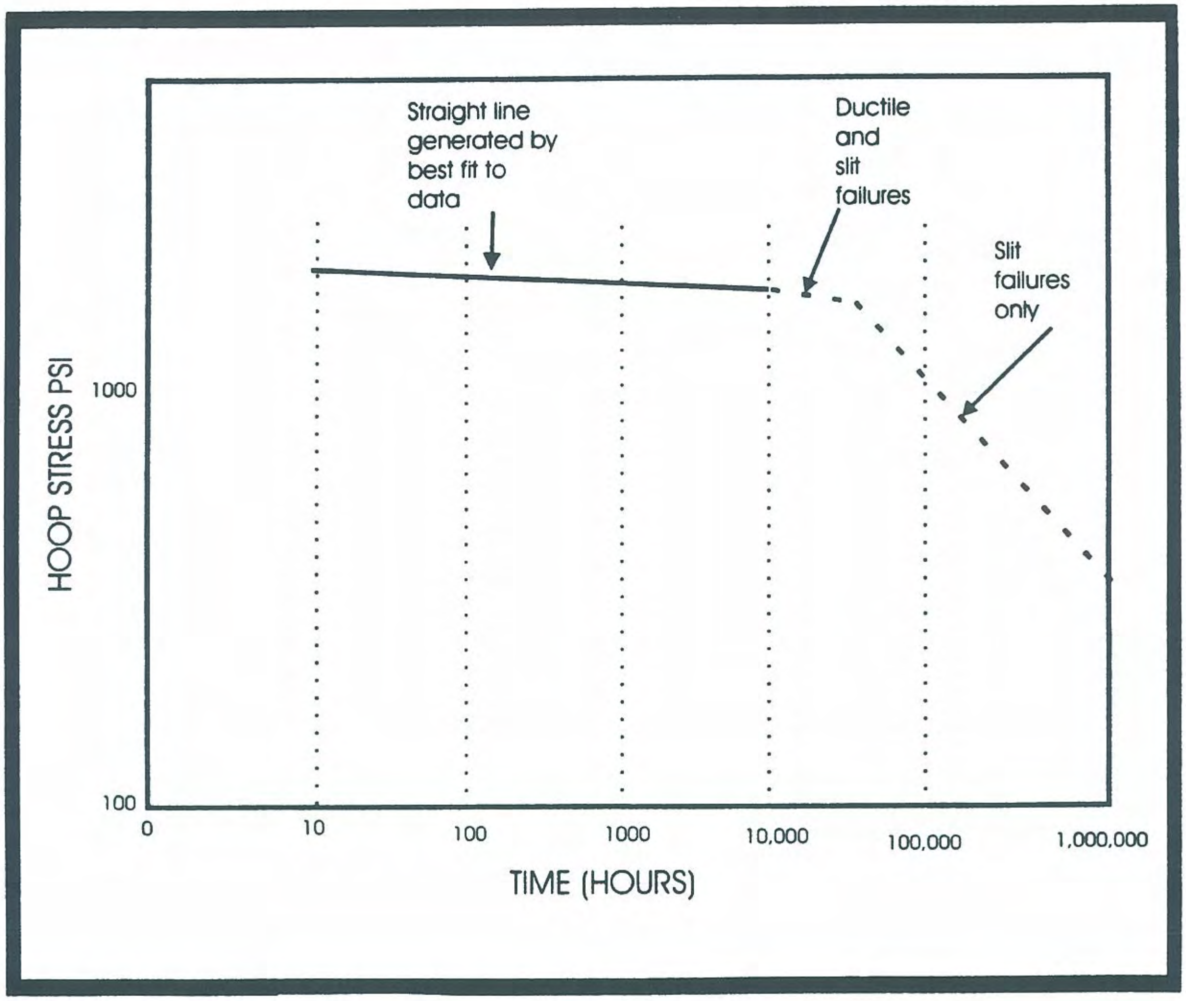

Figure 9 -- Stress rupture data plotted as best-fit straight line transitioning to downturn in strength. (Derived from *A.G.A. Plastic Pipe Manual for Gas Service.*)

improved elevated-temperature properties and improved longer term pipe performance, the PPI in 1982 recommended that ASTM D2513 specify a minimum acceptable hydrostatic strength at 140 °F. In 1984, ASTM D2513 included a statement in its non-mandatory appendix that gas pipe materials should have a specified long-term hydrostatic strength at 140 °F. In the 1988 edition, this requirement was moved to the mandatory section of the standard. This strength at 140 °F was calculated the same way that the 73 °F strength was calculated—data demonstrating a straight line to 10,000 hours was assumed to extrapolate to 100,000 hours without a downturn.

Gradually, more manufacturers obtained PPI listings for their resins intended for gas service, and by the early to mid-1980s, virtually all resins used for gas service had PPI listings. At that time, a consensus of manufacturers supported a change within ASTM D2513 to require PPI listings. In 1985, ASTM D2513 was revised to require that materials for gas service have a PPI listing.

By 1985, manufacturers reached a consensus to exclude materials that deviated from the 73 °F extrapolation before 100,000 hours. The PPI adopted this restriction and advised the industry that, effective January 1986, all materials not demonstrating straight-line performance to 100,000 hours would be dropped from its listing.[49] In 1988, ASTM D2837 also included the restriction.[50] The new PPI and ASTM requirements had no effect on pipe installed prior to the effective date of the requirements.

On August 20, 1997, after manufacturers reached a consensus, the PPI issued notice that, effective January 1999, in order for materials to retain their PPI listings for long-term hydrostatic strength at temperatures above 73 °F (for example, at 140 °F), these materials will have to demonstrate (mathematically, via elevated-temperature testing) that a downturn does not exist prior to 100,000 hours or, alternatively, if a downturn does exist before 100,000 hours, the strength rating will be reduced to reflect the point at which the calculated downturn in strength intercepts 100,000 hours. An ASTM project has been initiated to incorporate this requirement within ASTM D2837. The Safety Board also notes that the PPI has endorsed a proposal to have ASTM D2513 require polyethylene piping to have no downturn in stress rupture testing at 73 °F before 50 years, as mathematically determined in elevated-temperature tests.

All available evidence indicates that polyethylene piping's resistance to brittle-like cracking has improved significantly through the years. Several experts in gas distribution plastic piping have told the Safety Board that a majority of the polyethylene piping manufactured in the 1960s and early 1970s had poor resistance to brittle-like cracking, while only a minority of that manufactured by the early 1980s could be so characterized.[51] Several gas system operators have told the Safety Board that they are aware of no instances of brittle-like cracking with their own modern polyethylene piping installations.

Century Pipe Evaluation and History

The Safety Board's investigation of the Waterloo, Iowa, accident determined that the pipe involved in the accident had been manufactured by Amdevco Products Corporation (Amdevco) in Mankato, Minnesota. Amdevco's Mankato plant first began producing plastic pipe in 1970, with plastic piping for gas service as its only piping product. Amdevco made the pipe from Union Carbide's Bakelite DHDA 2077 Tan 3955 (hereinafter referred to as DHDA 2077 Tan) resin material. Century Utility Products, Inc., marketed the pipe to Iowa Public Service Company,[52] and Century's name was marked on the pipe. Century and Amdevco formally merged in 1973. The combined corporation went out of business in 1979.

Because Amdevco/Century no longer exists, Safety Board investigators could locate no records to indicate the qualification steps Amdevco may have performed before Century marketed its pipe to Iowa Public Service Company. A plastic pipe manufacturer would normally have obtained documentation from its resin supplier indicating that the resin material had a sufficient long-term hydrostatic strength. Code B31.8 required and ASTM D2513 recommended that polyethylene pipe manufacturers perform certain quality control tests on production samples, including twice-per-year sustained pressure tests.

Like many gas operators of that time, Iowa Public Service Company (now MidAmerican Energy Corporation), which had installed the Waterloo piping in 1971, had no formal program for testing or evaluating products. According to MidAmerican Energy, the company accepted representations from a principal of Century, a former DuPont employee, who portrayed himself as being intimately involved with the development and marketing of DuPont's polyethylene piping. MidAmerican Energy has reported that these representations included assertions that Century

[49]Mruk, S. A., "Validating the Hydrostatic Design Basis of PE Piping Materials."

[50]*A.G.A. Plastic Pipe Manual for Gas Service*, American Gas Association, Catalog No. XR 9401, 1994.

[51]A number of these experts considered material to have poor resistance to brittle-like cracking if the material was shown to have a downturn in strength associated with brittle-like fractures in stress rupture testing (at 73 °F) before 100,000 hours.

[52]Because of a series of organizational changes and mergers, the name of the owner/operator of the gas system at Waterloo, Iowa, has changed over the years. In 1971, Iowa Public Service Company installed the gas service that ultimately failed. At the time of the accident, the gas system operator was Midwest Gas Company. The current operator is MidAmerican Energy Corporation.

plastic pipe met industry standards and had the same formulation as DuPont's plastic pipe. In 1970, according to MidAmerican Energy officials, Century offered Iowa Public Service Company attractive commercial terms for its product, with the result that, in 1970, when Amdevco first started to manufacture pipe, Iowa Public Service Company began purchasing all of its plastic pipe from Century.[53]

Before the Waterloo accident, a previous accident involving Century pipe had been reported in the Midwest Gas (the operator at the time of the accident) system. That accident occurred in August 1983 in Hudson, Iowa, and resulted in multiple injuries. Midwest Gas, attributing this accident to a rock pressing into the pipe, considered it an isolated incident. During 1992-94, the company had two significant failures with pipe fittings involving brittle-like cracks in Century pipe. Sections of the failed pipe were sent to the two affected pipe fitting manufacturers, and one responded that nothing was wrong with the fitting, suggesting instead that the problem might rest with the piping material.

MidAmerican Energy reported that, as a result of these two failures, Midwest Gas directed inquiries to other utilities operating in the Midwest and, in May 1994, learned of one other accident involving Century pipe. In June 1994, Midwest Gas decided to send samples of Century polyethylene piping to an independent laboratory for test and evaluation. The sample collection was in process at the time of the Waterloo accident. In August 1995, Midwest Gas issued a report, based on the laboratory testing, concluding that the Century samples had poor resistance to slow crack growth.

Subsequent to the accident, Midwest Gas worked to determine if its installations with Century plastic piping had had higher rates of failure than those with piping from other manufacturers. After analyzing the data, Midwest Gas concluded that the piping installations with Century piping had failure rates that were significantly higher than those installations with plastic piping from other manufacturers. Based on this analysis, as well as on other factors—including the severity and consequences of leaks involving Century piping, the laboratory test results, recommendations from two manufacturers of pipe fittings cautioning against use of their fittings with Century pipe because of the pipe's poor resistance to brittle-like cracking, and interviews with field personnel—MidAmerican Energy (the current operator) has replaced all its known Century piping with new piping, completing the replacement program in 1997.

Safety Board investigators found little additional documentation regarding qualification tests of Century plastic pipe by other gas system operators having Century pipe in service. A reference was found to a 1971 Northern States Power Company Testing Department progress report stating that Century pipe complied with ASTM D2513, and that the pipe was acceptable for use with DuPont polyethylene fittings. The actual progress report and records of any tests that may have been performed were not located.[54]

Union Carbide DHDA 2077 Tan Resin -- The resin used to manufacture the pipe involved in the Waterloo accident was DHDA 2077 Tan. To examine how Union Carbide qualified this material requires some background.

During the late 1960s, several companies manufactured plastic resin and plastic pipe for the gas distribution plastic piping market. At that time, Union Carbide began a process of modifying its DHDA 2077 Black resin (for water distribution) in order to create a DHDA 2077 Tan resin for the gas distribution industry.

Before Union Carbide could market its DHDA 2077 Tan resin material for natural gas service, it needed to generate stress rupture data, in accordance with the PPI procedure, that would support the long-term hydrostatic

[53] Iowa Public Service Company continued to purchase DuPont plastic piping fittings until fittings were available from Century. MidAmerican Energy made technical procurement decisions via a Gas Standards Committee. According to company officials, the company has implemented a process to ensure that it continues to receive quality products once the products have passed an initial qualification process.

[54] Northern States Power is based in St. Paul, Minnesota.

strength rating it was assigning to the material (a requirement of the interim Federal regulations effective at that time).[55] The company had three resources to draw upon to support the hydrostatic design basis category: (1) internal stress rupture data on its DHDA 2077 Tan resin, (2) a PPI listing already obtained on its similar black resin, and (3) additional internal stress rupture data on its black resin.

On June 11, 1968, Union Carbide began stress rupture testing on specimens of pipe made from a pilot-plant batch of its newly developed DHDA 2077 Tan resin. The results of this testing supported Union Carbide's declared hydrostatic design basis category for DHDA 2077 Tan. The number of data points generated by these stress rupture tests for the DHDA 2077 Tan was less than that required by PPI procedure; however, Union Carbide began to market the product for use in gas systems based on these tests and on additional testing performed on the company's black resin material.

Because Union Carbide had not developed the PPI-prescribed number of data points on its DHDA 2077 Tan resin before marketing the product, Safety Board investigators reviewed the data the company developed on its black resin. A review of Union Carbide's laboratory notebooks revealed that a number of adverse data points Union Carbide developed for its black resin were not submitted to the PPI when the company applied for a PPI listing for the black material.[56]

Union Carbide first made a commercial version of its DHDA 2077 Tan resin during the spring of 1969, and in April 1970, a first shipment of 80,000 pounds of DHDA 2077 Tan resin was shipped to Amdevco's Mankato plant. The next shipment of the material to Amdevco was not until 1971. Based on Amdevco's June 11, 1970, manufacturing date for the Waterloo pipe, Union Carbide manufactured, sold, and delivered the resin used to make the Waterloo pipe between the spring of 1969 and June 11, 1970, and the resin used to make the pipe involved in the Waterloo accident probably was included in the April 1970 shipment.

Union Carbide began, on December 3, 1970, additional stress rupture tests on its commercial DHDA 2077 Tan resin. These tests generated the results to further support its claimed long-term hydrostatic strength and also provided the number of data points required by the PPI procedure. Additional stress rupture tests on the commercial DHDA 2077 Tan resin beginning on December 28, 1970, and again on January 6, 1972, further supported the material's long-term hydrostatic strength.

During the late 1960s and 1970s, Minnegasco, a gas system operator based in Minneapolis, Minnesota, routinely employed a 1,000-hour sustained pressure test at 100 °F detailed in ASTM D2239 and a 1,000-hour sustained pressure test at 73 °F detailed in ASTM D2513 to qualify plastic piping for use in its system. Minnegasco went beyond the requirements of ASTM standards by continuing both versions of the testing beyond 1,000 hours until eventual failure occurred. The company used this information to evaluate the relative strengths of different brands of piping.

In 1969-70, Minnegasco began a series of tests on samples from five different suppliers of plastic piping made from DHDA 2077 Tan resin. On March 3, 1972, Minnegasco's laboratory issued an internal report that contained the results of its latest tests on piping made from the resin and referenced earlier tests on several brands of piping (including Amdevco/Century) that were also made from it. Based on this report, Minnegasco rejected for use in its gas system the DHDA 2077 Tan resin. According to the report, the company rejected the material because (1) none of the pipe samples made from this resin could consistently pass the 1,000-hour sustained pressure test at

[55]The company was required to follow the PPI procedure in developing the necessary stress rupture data, but no requirement existed for those data to be submitted to the PPI or for the PPI to assign a listing before the tested material could be marketed.

[56]Although the PPI procedure required the submission of all valid data points for statistical analysis, the Union Carbide employee who managed the data indicated that he believed he could discard data that, in his judgment, did not adequately characterize the material's performance. Union Carbide has contended that the non-submitted data may have been invalid because of experimental error, uncompleted tests, or other reasons.

100 °F, and (2) the pipe samples had lower performance in 73 °F sustained pressure tests than similar plastic piping materials already in use in the company's gas system.

In 1971, Union Carbide acknowledged to a pipe manufacturer that piping material manufactured by DuPont had a higher pressure rating at 100 °F than did its own DHDA 2077 Tan. Union Carbide laboratory notebooks examined by the Safety Board showed test results for the DHDA 2077 Tan material that generally met the 1,000-hour sustained pressure test value at both 100 °F and 73 °F, although, in the case of the 100 °F test, not by a wide margin. The notebooks also showed that the material had an early ductile-to-brittle transition point in stress rupture tests.[57]

Information Dissemination Within the Gas Industry

The OPS reports that more than 1,200 gas distribution or master meter system[58] pipeline operators submit reports to the OPS. Additionally, more than 9,000 gas distribution or master meter system pipeline operators are subject to oversight by the States.

As noted earlier, a frequent failure mechanism with polyethylene piping involves crack initiation and slow crack growth. These brittle-like fractures occur at points of stress intensification generated by external loading acting in concert with internal pressure and residual stresses.[59]

A 1985 paper[60] analyzed, for linear (straight line) behavior up to 100,000 hours, the stress rupture test performance (by elevated-temperature testing) of six polyethylene piping materials. The results were then correlated with field performance. This paper found that those materials that did not maintain linearity through 100,000 hours had what the author characterized as "known poor" or "questionable" field performance. On the other hand, those materials that maintained linearity through 100,000 hours had what the author characterized as "known good" field performance through their 20-year history logged as of 1985.

By the early to mid-1980s, the industry had developed a method to mathematically relate failure times to temperatures and stresses during stress rupture testing.[61] In the early 1990s, the industry developed "shift functions," another mathematical method to relate failure times to temperatures and stresses.[62]

One study[63] pointed out that using mathematical methods to calculate the remaining service life of pipe under the assumption that the pipe would only be exposed

[57]The data from the laboratory notebooks suggest that this material's early ductile-to-brittle transition would not have met today's standards.

[58]*Master meter system* refers to a pipeline system that distributes gas to a definable area, such as a mobile home park, a housing project, or an apartment complex, where the master meter operator purchases gas for resale to the ultimate consumer.

[59]Kanninen, M. F., O'Donoghue, P. E., Popelar, C. F., Popelar, C. H., Kenner, V. H., *Brief Guide for the Use of the Slow Crack Growth Test for Modeling and Predicting the Long-Term Performance of Polyethylene Gas Pipes*, Gas Research Institute Report 93/0105, February 1993. Because, after extrusion, the outside of the pipe cools before the inside, residual stresses are usually developed in the wall of the pipe.

[60]Mruk, S. A., "Validating the Hydrostatic Design Basis of PE Piping Materials."

[61]Bragaw, C. G., "Prediction of Service Life of Polyethylene Gas Piping System," *Proceedings Seventh Plastic Fuel Gas Pipe Symposium*, pp. 20-24, 1980, and Bragaw, C. G., "Service Rating of Polyethylene Piping Systems by the Rate Process Method," *Proceedings Eighth Plastic Fuel Gas Pipe Symposium*, pp. 40-47, 1983, and Palermo, E. F., "Rate Process Method as a Practical Approach to a Quality Control Method for Polyethylene Pipe," *Proceedings Eighth Plastic Fuel Gas Pipe Symposium*, pp. 96-101, 1983, and Mruk, S. A., "Validating the Hydrostatic Design Basis of PE Piping Materials," and Palermo, E. F., "Rate Process Method Concepts Applied to Hydrostatically Rating Polyethylene Pipe," *Proceedings Ninth Plastic Fuel Gas Pipe Symposium*, pp. 215-240, 1985.

[62]Popelar, C. H., "A Comparison of the Rate Process Method and the Bidirectional Shifting Method," *Proceedings of the Thirteenth International Plastic Fuel Gas Pipe Symposium*, pp. 151-161, and Henrich, R. C., "Shift Functions," *1992 Operating Section Proceedings*, American Gas Association.

[63]Broutman, L. J., Bartelt, L. A., Duvall, D. E., Edwards, D. B., Nylander, L. R., Stellmack-Yonan, M., *Aging of Plastic Pipe Used for Gas Distribution, Final Report*, Gas Research Institute report number GRI-88/0285, December 1988.

to stresses of internal operating pressures would result in unrealistically long service-life predictions. As noted earlier, polyethylene piping systems have failed at points of long-term stress intensification caused by external loading acting in concert with internal pressure and residual stresses; thus, to obtain a realistic prediction of useful service life, stresses from external loadings need to be acknowledged.

Over a number of years, the Gas Research Institute (GRI) sponsored research projects investigating various tests and performance characteristics of polyethylene piping materials. Among these projects was a series of research investigations directed at exploring the fracture mechanics principles behind crack initiation and slow crack growth. These investigations led to the development of slow crack growth tests. The research studies frequently identified the piping and resins studied by codes rather than by specific materials, manufacturers, or dates of manufacture.

In 1984, the GRI published a study[64] that compared and ranked several commercially extruded polyethylene piping materials produced after 1971. Again, the materials tested were identified by codes. Stress rupture tests were performed using methane and nitrogen as the internal pressure medium and air as the outside environment. Several stress rupture curves showed early transitioning from ductile to brittle failure modes.

The A.G.A.'s Plastic Materials Committee periodically updates the *A.G.A Plastic Pipe Manual for Gas Service*, which addresses a number of issues covered by this Safety Board special investigation. In 1991, the committee formed a task group to gather and then disseminate to the industry information regarding the performance of older plastic piping systems. The task group disbanded in 1994 without issuing a report.

In 1982 and 1986, DuPont formally notified its customers about brittle-like cracking concerns with the company's pre-1973 pipe. Safety Board investigators could find no record of either Century/Amdevco, Union Carbide, or any other piping or resin manufacturer formally notifying the gas industry of the susceptibility to premature brittle-like failures of their products. Nor does any mechanism exist to ensure that the OPS receives safety-related information from manufacturers.

Regarding Federal actions on this issue, the OPS has not informed the Safety Board of any substantive action it has taken to advise gas system operators of the susceptibility to premature brittle-like failures of any older polyethylene piping.[65]

Installation Standards and Practices

The discussion in this section is intended to present a "snapshot" of the regulations and some of the primary standards, practices, and guidance to prevent stress intensification at plastic service connections to steel tapping tees. The appendix to this report includes a description of the connection in the Waterloo accident, and figure 10 provides a close-up view of the failed fitting.

Federal Regulations -- The OPS establishes, in 49 CFR 192.361, minimum pipeline safety standards for the installation of gas service piping.

Paragraph 192.361(b) reads as follows:

> *Support and backfill.* Each service line must be properly supported on undisturbed or well-compacted soil....

Paragraph 192.361(d) reads:

> *Protection against piping strain and external loading.* Each service line must be installed so as to minimize anticipated piping strain and external loading.

[64]Cassady, M. J., Uralil, F. S., Lustiger, A., Hulbert, L. E., *Properties of Polyethylene Gas Piping Materials Topical Report (January 1973 - December 1983)*, GRI Report 84/0169, Gas Research Institute, Chicago, IL, 1984.

[65]The Safety Board asked the OPS for information about its actions in regard to older piping, after which, in 1997, the OPS notified State pipeline safety program managers of several issues regarding Century pipe and solicited input on their experiences with this particular piping.

Figure 10 -- Close-up view of failed plastic pipe connection to steel tapping tee from site of Waterloo, Iowa, accident. A portion of the fractured plastic service line (light-colored material) remains attached to the tee.

Subsequent to the Waterloo accident, personnel from the Iowa Department of Commerce, after discussions with OPS personnel, stated that the Waterloo installation was not in violation of the Federal regulation. They further stated that, while they agree that the installation of protective sleeves[66] at pipeline connections is prudent, a specific requirement to install protective sleeves is beyond the scope of Part 192 and is inconsistent with the regulation's performance orientation.

The Transportation Safety Institute (TSI), part of RSPA, conducts training classes for Federal and State pipeline inspectors. TSI instructors advise class participants that many of the performance-oriented regulations within Part 192 can only be found to be violated if the gas system fails in a way that demonstrates that the regulation was not followed. The TSI acknowledges the difficulty of identifying violations under paragraph 192.361(d). A TSI instructor told the Safety Board that, in the case of the failed pipe at Waterloo, an enforcement action faulting the installation would be unlikely to prevail because of the poor brittle-like crack resistance of the failed pipe and the length of time (23 years) between the installation and failure dates.

GPTC Guide for Gas Transmission and Distribution Piping Systems -- After the adoption of the Natural Gas Pipeline Safety Act in August 1968, the American Society of Mechanical Engineers, after discussions with

[66]Protective sleeves are intended to help shield the pipe at the connection point from bearing loads and shear forces and to limit the maximum pipe bending.

the Secretary of Transportation, formed the Gas Piping Standards Committee (later renamed the Gas Piping Technology Committee) to develop and publish "how-to" specifications for complying with Federal gas pipeline safety regulations. The result was the *GPTC Guide for Gas Transmission and Distribution Piping Systems* (GPTC Guide). The GPTC Guide lists the regulations by section number and provides guidance, as appropriate, for each section of the regulation.

In its investigation of the previously referenced 1971 accident in Texas, the Safety Board determined that protective sleeves were too short to fully protect a series of service connections to a main. The Safety Board noted that a protective sleeve must have the correct inner diameter and length if it is to protect the connection from excessive shear forces. As a result, and in response to a Safety Board safety recommendation,[67] the 1974 and later editions of the GPTC Guide included guidance that "a protective sleeve designed for the specific type of connection should be used to reduce stress concentrations." No guidance was included as to the importance of a protective sleeve's length, diameter, or placement.[68]

The GPTC Guide does not include recommendations to limit bending in plastic piping during the installation of service lines under 49 CFR 192.361. Although the guide references the *A.G.A. Plastic Pipe Manual for Gas Service*, and this manual does provide recommendations on bending limits, the GPTC Guide does not reference this manual in its guidance material under 49 CFR 192.361.

A.G.A. Plastic Pipe Manual for Gas Service -- The most recent edition of the *A.G.A. Plastic Pipe Manual for Gas Service*[69] identifies the connection of plastic pipe to service tees as "a critical junction" needing installation measures "to avoid the potentially high...stresses on the plastic at this point." The manual recommends proper support and the use of protective sleeves. Although the manual recommends following manufacturers' recommendations, no guidance is included on the importance of a protective sleeve's proper length, diameter, or placement. The manual includes, without elaboration, the following sentence:

> Installation of the tee outlet at angles up to 45° from the vertical or along the axis of the main as a 'side saddle' or 'swing joint' may be considered to further minimize...stresses.

The 1994 edition adds that manufacturers' recommended limits on bending at fittings may be more restrictive than for a run of piping alone.

A.G.A. Gas Engineering and Operating Practices (GEOP) Series -- The preface to the current *Distribution Book D-2* of the GEOP series states that the intent of the books is to offer broad general treatment of their subjects, and that listed references provide additional detailed information.

Figure 11 reproduces an illustration from *Book D-2.* This figure shows a steel tapping tee with a compression coupling joint connected to a plastic service. The illustration shows a protective sleeve and includes a note to extend the protective sleeve to undisturbed or compacted soil or to blocking. But the figure also shows the blocking positioned so that either the edge of the blocking or the edge of the protective sleeve might provide a fixed contact point on the plastic service pipe if the weight of backfill were to cause the pipe to bend down. Additional illustrations within this GEOP series book show this same positioning of the blocking with respect to the plastic pipe.

ASTM -- The most recent ASTM standard covering the installation of polyethylene piping was revised in 1994.[70] This standard addresses

[67] Safety Recommendation P-72-64 from National Transportation Safety Board Pipeline Accident Report-- *Lone Star Gas Company, Fort Worth, Texas, October 4, 1971.*

[68] The correct positioning of the protective sleeve has a bearing on its effective length.

[69] *A.G.A. Plastic Pipe Manual for Gas Service*, American Gas Association, Catalog No. XR 9401, 1994.

[70] ASTM D2774-94, *Standard Practice for Underground Installation of Thermoplastic Pressure Piping*, American Society for Testing and Materials, 1994.

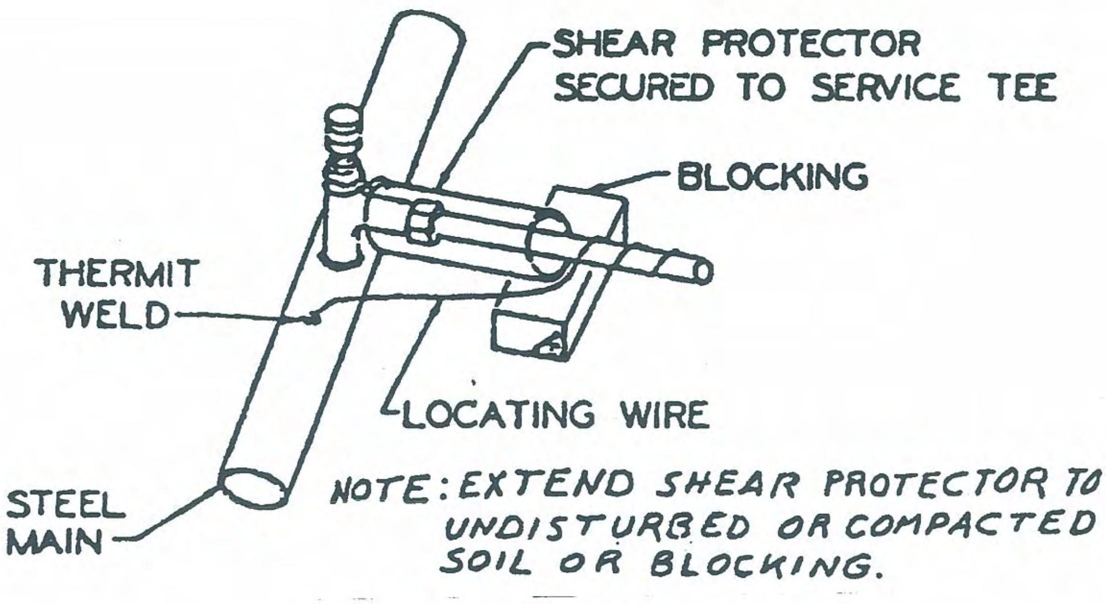

Figure 11 -- Reproduction from A.G.A. GEOP series illustrating application of protective sleeve. (Hand-scribed notation from the original.)

the vulnerability of the point-of-service connection to the main.

This standard, advising consultation with manufacturers, recommends taking extra care during bedding and backfilling to provide for firm and uniform support at the point of connection. In addition, the document recommends minimizing bends near tap connections, generally recommending that bends occur no closer than 10 pipe diameters from any fitting and that manufacturers' bend limits be followed. Similar recommendations for avoiding bends close to a fitting can be found in the forward to a water industry standard.[71]

This ASTM standard further recommends the use of a protective sleeve if needed to protect against possible differential settlement. Currently, manufacturers that provide protective sleeves have their own criteria for designing sleeve lengths and diameters for their fittings. Some manufacturers' criteria are based on limiting stress to a maximum safe value,[72] while one manufacturer has advised the Safety Board that its sleeve is not designed to limit bending, but only to guard against shear forces at the connection point.

Guidance Manual for Operators of Small Natural Gas Systems -- The OPS/RSPA *Guidance Manual for Operators of Small Natural Gas Systems* notes that plastic pipe failures have been found at transitions between plastic and metal pipes at mechanical fittings. The manual states the need to firmly compact soil under plastic pipe, advises following manufacturers' instructions for proper coupling procedures, and shows protective sleeves on connections of plastic services to steel tapping tees. The manual indicates that a properly designed protective sleeve should be used. The manual does not caution against bending the piping in proximity to a connection.

[71]Forward to American Water Works Association Standard C901-96, *AWWA Standard for Polyethylene (PE) and Tubing, ½ In. (13 mm) Through 3 In. (76 mm) for Water Service*, effective March 1, 1997.

[72]Allman, W. B., "Determination of Stresses and Structural Performance in Polyethylene Gas Pipe and Socket Fittings Due to Internal Pressure and External Soil Loads," *1975 Operating Section Proceedings*, American Gas Association, 1975.

Manufacturers' Recommendations -- As noted earlier, both the *A.G.A. Plastic Pipe Manual for Gas Service* and ASTM D2774 specifically refer the reader to manufacturers for further guidance on limiting shear and bending forces at plastic service connections made to steel mains via steel tapping tees.

Bending and Shear Forces -- Safety Board investigators contacted representatives of the four principal companies that marketed plastic piping for gas service to determine to what extent plastic piping manufacturers were providing recommendations for limiting shear and bending forces at plastic service connections to steel mains via steel tapping tees. The four manufacturers contacted were CSR PolyPipe, Phillips Driscopipe, Plexco, and Uponor Aldyl Company (Uponor).

Three out of four of these manufacturers had published recommendations addressing these issues. These three manufacturers have historically emphasized heat fusion fitting systems[73] instead of field-assembled mechanical fitting systems. Representatives of these manufacturers indicated that mechanical fittings manufacturers should provide installation instructions covering their systems. Accordingly, one of the manufacturers' published literature referred the reader to the manufacturers of mechanical fittings for installation instructions. Nonetheless, these three major polyethylene pipe manufacturers did, in fact, provide recommendations to limit shear and bending forces, and these recommendations can apply to plastic service connections to steel mains via steel tapping tees.

With respect to the specific issue of limiting bends, DuPont, in January 1970, issued recommendations to limit bends for polyethylene pipe. DuPont/Uponor[74] later published bend radius recommendations that differentiated between pipe segments consisting of pipe alone and those with fusion fittings. The recommendations specified much less bending for pipe segments with fusion fittings; however, DuPont/Uponor did not provide bend limits for mechanical fittings. Two of the other major manufacturers (Phillips Driscopipe and Plexco) provide bend limits and differentiate between pipe alone and pipe with fittings, without specifying the type of fittings. None of the manufacturers' literature discusses bending with or against any residual bend remaining in the pipe after it is uncoiled. (See "Pipe Residual Bending" below.)

Of these four major polyethylene gas pipe manufacturers, only CSR PolyPipe had no published recommendations for limiting shear and bending forces at plastic service connections to steel mains via steel tapping tees. Although the company does not manufacture steel tapping tees with compression ends for attachment to plastic services, it does manufacture pipe that will be attached to steel tapping tees via mechanical compression couplings. The company has been supplying polyethylene pipe to the gas industry since the 1980s[75] and is thus relatively new to that business compared to the other three major manufacturers. When CSR PolyPipe entered the market, plastic materials were vastly improved compared to earlier versions with respect to resistance to crack initiation and slow crack growth. For this reason, according to CSR PolyPipe personnel, the company saw less need to publish installation recommendations.

The Safety Board attempted to identify every U.S. steel tee manufacturer that currently manufactures steel tees with a compression end for plastic gas service connections.[76] The Safety Board identified and contacted representatives of Continental Industries (Continental), Dresser Industries, Inc. (Dresser), Inner-Tite Corp. (Inner-Tite),[77] and Mueller Company (Mueller).

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[73]Heat fusion fittings are used to make piping joints by heating the mating surfaces and pressing them together so that they become essentially one piece.

[74]Uponor purchased DuPont's plastic pipe business in 1991.

[75]CSR Hydro Conduit Company purchased PolyPipe in 1995. PolyPipe began supplying polyethylene pipe to the gas industry in the 1980s.

[76]J. B. Rombach, Inc., which manufactures M. B. Skinner Pipeline products, told the Safety Board that it no longer manufactures or markets its "Punch-It-Tee" line of steel tapping tees. Chicago Fittings Corporation told the Safety Board it no longer manufactures or markets its line of steel tapping tees. The Safety Board therefore made no further inquiry with these companies.

[77]Inner-Tite did not manufacture steel tees; it purchased them, affixed its own compression connections,

Only Continental and Inner-Tite offered protective sleeves to their customers as an option. None of these manufacturers has published installation recommendations to limit shear and bending forces on the plastic pipe that connects to their steel tapping tees.

On another issue related to protective sleeves, Safety Board examination of a protective sleeve offered by Continental to its customers revealed that the sleeve that did not have sufficient clearance to allow the application of field wrap (intended to protect the steel tee from corrosion after it is in the ground) to that portion of the steel tee under the sleeve. This observation was confirmed by a Continental representative.

Pipe Residual Bending -- The service involved in the Waterloo accident was installed with a bend at the connection point to the main. (See illustration in appendix A.) The plastic service pipe leaving the tee immediately curved horizontally. The pipe was cut out and brought into the laboratory, at which time the bend had a measured horizontal radius of approximately 34 inches. Based on field conditions and photos, MidAmerican Energy estimated the original installed horizontal bend radius to have been about 32 inches. This bend is sharper than that allowed by current industry installation recommendations for modern piping adjacent to fittings.

An issue related to recommended bend radius is residual pipe bending. Plastic pipe often arrives at a job site in banded coils. After the bands are released, the coiled pipe will partially straighten, but some residual bending will remain. The water industry already recognizes that bends *in* the direction of the residual coil bend should be treated differently than bends *against* the direction of the bend;[78] however, gas industry field bend radius recommendations do not address residual coil bending.

A former Iowa Public Service Company employee stated that Iowa Public Service Company, in an effort to reduce stress at connection points, generally attempted to install polyethylene services at an angle to the main to match the residual bend left after uncoiling the pipe. This former employee stated that no set time was specified to allow for complete relaxing of the pipe, but that the pipe would be placed in the ditch, and the crews would weld the tee at what they judged to be the appropriate angle.

MidAmerican Energy Installation Standards -- As a result of the Waterloo accident, Safety Board investigators examined some of MidAmerican Energy's construction standards for minimizing shear and bending forces at plastic service connection points to steel mains. Specifically, Safety Board investigators examined MidAmerican Energy's standards pertaining to providing firm support, using protective sleeves, and limiting bends at plastic service connections to steel mains.

According to the company, MidAmerican Energy no longer installed steel tapping tees with mechanical compression ends to connect to plastic service pipe. Instead, it employed steel tapping tees welded at the factory to factory-made steel-to-plastic transition fittings. It then field-fused the plastic ends from the transition fittings to the plastic service pipe.

MidAmerican Energy advised the Safety Board that it had no standard calling for firm compacted support under plastic service connection points to steel mains.

MidAmerican Energy designed, constructed, and installed its own protective sleeves for installation on its purchased steel tapping tee/transition fitting assemblies. MidAmerican Energy required its protective sleeves to be a minimum of 12 inches long; however, MidAmerican Energy could provide no design criteria for this length. MidAmerican Energy has reported that the company's unwritten field practice was to install the smallest diameter sleeve that will clear the field wrapped fitting, but MidAmerican Energy had no written requirements or design criteria for the diameter of its protective sleeves. The company's standard showed the sleeve as approximately centered over the steel-to-plastic transition, and no

and marketed the complete assembly.

[78]Forward to American Water Works Association Standard C901-96.

criteria or instructions were provided for the correct positioning of the sleeves.

The Safety Board notes that manufacturers that provide factory-made steel-to-plastic transition fittings will also provide protective sleeves along with the transition fittings and will provide positioning guidance for their use.

Effective January 27, 1997, MidAmerican Energy instituted minimum bend radii requirements that differentiated between pipe segments consisting of pipe alone and pipe with fittings.

Gas System Performance Monitoring

This section examines gas system performance monitoring largely in the context of the Waterloo accident.

Federal regulations (49 CFR 192.613 and 192.617) require that gas pipeline system operators have procedures in place for monitoring the performance of their gas systems. These procedures must cover surveillance of gas system failures and leakage history, analysis of failures, submission of failed samples for laboratory examination (to determine the causes of failure), and minimizing the possibility of failure recurrences.

Prior to the Waterloo accident, Midwest Gas had two systems for tracking, identifying, and statistically characterizing failures. The first system was the leak data base, which tracked the status of leak reports, documented actions taken, and recorded almost all gas system leaks. The data base received input from two primary sources: leak reports from customers and leak survey results. The data base parameters classified the general type of piping material that leaked (such as "plastic," "cast iron," "bare steel"), and indicated whether the leak occurred in pipe or certain fittings. The parameters did not include manufacturers, manufacturing or installation dates, sizes,[79] or failure conditions commonly found with plastic piping (for example, poor fusions, bending force failures, insufficient soil compaction, rock impingement failures, and lack or improper use of protective sleeves). The data base indicated that the performance of plastic piping overall was comparable to other piping materials. MidAmerican Energy stated that the parameters chosen for this data base were those required for reporting to the DOT. The company said the parameters were also chosen on the premise that pipe meeting industry specifications would perform similarly.

[79]While sizes of the piping, along with a drawing of the piping assembly, were normally written or drawn on the forms, piping size was not captured in the data base generated by these forms.

The second system used by Midwest Gas for tracking failures was the company's material failure report data base, which was intended for use in evaluating the quality and performance histories of products installed in the company's gas system. Input to the data base was by way of a form (or, in some cases, a tag) filled out by field personnel. The form included categories such as the manufacturer, size, and an internal material identification number of the affected pipe or component. It also included areas for a narrative description of the failure. The form did not include dates of manufacture or installation dates or failure conditions commonly found on plastic piping. Field personnel sent the failed item, along with the completed form or tag, to engineering personnel, who examined the item and accompanying information to determine the need for corrections. Midwest Gas personnel then transcribed the narrative description of the failure word-for-word into the data base without attempting to determine and categorize causes of failure. Engineering personnel compiled the available data into periodically issued material summary reports. The company said engineering personnel from time to time sorted available data fields to determine trends.

The material failure report data base included only a portion of the leaks in the Midwest Gas system. For example, if Midwest Gas field personnel corrected a leak by replacing an entire line segment without digging up the leaking component (which the company said was a frequent occurrence with bare steel, cast iron, and certain plastic piping that was difficult to join), the material failure report data base system was not used. Also, field personnel were not required to use the reporting system if they determined that the failed item was related to an operating problem, such as excavation damage, rather than to a material problem.

Additionally, the company indicated that the system did not enjoy full participation from field personnel.

When, after the Waterloo accident, Midwest Gas attempted to determine if installations with Century plastic piping had higher rates of failure than those with piping from other manufacturers, it found that its material failure report data base's incomplete coverage of gas leaks made that data base unsuitable for the purpose. The company decided instead to use the leak data base, which the company believed included almost all leaks. But because the leak data base did not list the manufacturers of plastic piping, Midwest Gas took several months to correlate entries in the leak data base with records showing the manufacturers of plastic piping. Midwest Gas, in 1995, concluded that piping installations with Century piping had failure incidence rates that were significantly higher than the balance of its plastic piping system. The company did not correlate entries with the years of installation.

Since the Waterloo accident, the current Waterloo gas system operator, MidAmerican Energy, in addition to replacing all its Century pipe, has added parameters such as piping size, installation date, and pressure to the forms used for input into its leak data base. Also since the accident, MidAmerican Energy has added parameters such as installation date, pressure, and component location and position to its form for input into its material failure report data base. The company has also worked to determine if any other plastic piping manufacturers can be linked to piping with unacceptable performance.

The current (1994) edition of the *A.G.A. Plastic Pipe Manual for Gas Service* recommends the use and provides a sample of a form for recording information on plastic piping failures. The manual recommends collecting this information and then performing a visual examination or, in some cases, a laboratory analysis, to determine the type and cause of failure.

ANALYSIS

General

The common thread in a series of plastic pipeline accidents investigated by the Safety Board and others since the early 1970s—as well as in a number of reports of other, non-accident, plastic pipeline leaks—is the indicated presence of brittle-like cracking leading to eventual pipe failure. The number and similarity of these brittle-like failures seem to indicate that the long-term durability of plastic piping, which was premised on the pipe's ductility, may have been overstated by the method used to rate the long-term strength of plastic piping materials.

Based on the available evidence, any public safety threat posed by possible premature failure of plastic piping appears to be limited to locations where stress intensification exists. This special investigation examines in detail one installation configuration—plastic pipe mechanical connections to steel mains via steel tapping tees—where great potential exists for the generation of stress intensification. At these connections, certain poor installation practices have been known to create stress that is greater than the pipe can withstand. Thus, inadequate or improper installation of piping connections, in combination with brittle piping, represents one identifiable public safety hazard associated with the thousands of miles of older plastic piping now in service nationwide.

Gas system operators need to have an effective surveillance and data analysis (performance monitoring) program to determine the extent of the possible hazard associated with their pipeline systems, including plastic piping. Such a program must be adequate to detect trends as well as to identify localized problem areas, and it must be able to relate poor performance to specific factors such as plastic piping brands, dates of manufacture (or installation dates), and failure conditions.

The major safety issues developed during this special investigation are as follows:

- The vulnerability of plastic piping to premature failures due to brittle-like cracking;
- The adequacy of available guidance relating to the installation and protection of plastic piping connections to steel mains; and
- Performance monitoring of plastic pipeline systems as a way of detecting unacceptable performance in piping systems.

The remainder of this analysis addresses each of these major safety issues, as well as a number of other issues affecting the safety of plastic piping for gas service.

Durability of Century Utility Products Piping

Iowa Public Service Company, the company that installed the Century pipe involved in the 1994 Waterloo, Iowa, pipeline accident, began purchasing all of its plastic pipe from Century in 1970, when Amdevco/Century had just started to manufacture plastic pipe. These purchases were made without Iowa Public Service Company's having a testing or technical evaluation program and without Century/Amdevco having a successful track record. Iowa Public Service Company decided on the Century product because Century offered favorable commercial terms for a product it claimed was virtually identical to the DuPont plastic piping that had previously been used.

The Safety Board has investigated two other pipeline accidents, one in Nebraska in 1978 and one in Minnesota in 1983, that involved Century piping. The Safety Board is also aware of four other accidents that it did not investigate that involved the same brand of piping. Moreover, laboratory testing of Century product samples from the Waterloo accident determined that the material had the same brittle-like crack properties that have been associated with materials having poor performance histories.

Laboratory examination also revealed evidence of slow crack growth typical of brittle-like cracking.

The Century pipe involved in the Waterloo accident was made from Union Carbide's DHDA 2077 Tan resin. Although Union Carbide's laboratory data indicated that the material had the strength required by existing government and industry requirements, the Safety Board's review of the same data showed that the material had an early ductile-to-brittle transition, indicating poor resistance to brittle-like fractures.

In the early 1970s, a Minnesota gas system operator tested a number of piping products made from DHDA 2077 Tan resin, including those marketed by Century, as part of its comprehensive specification, testing, and evaluation program. The company rejected piping made from the Union Carbide product for use in its system based on the results of sustained pressure tests. Union Carbide, in 1971, acknowledged that its DHDA 2077 Tan resin material had a lower pressure rating at 100 °F than did DuPont's polyethylene pipe material.

Midwest Gas, the Waterloo, Iowa, gas operator at the time of the explosion and fire, had experienced at least three other significant failures involving Century pipe. The most recent failures, occurring between 1992 and 1994, prompted the company to collect samples of the Century material for independent laboratory testing. Samples were being gathered for testing at the time of the Waterloo accident. The subsequent laboratory report indicated that the Century piping had poor resistance to slow crack growth.

Midwest Gas's subsequent analysis of the company's leakage history concluded that its installations with Century piping had failure rates significantly higher than those with piping from other manufacturers. Midwest Gas had received warnings from two pipe fitting manufacturers against use of their products with Century pipe because of Century pipe's susceptibility to brittle-like cracking. The current operating company in the Waterloo, Iowa, area, MidAmerican Energy, has, since the accident, replaced all the identified Century piping in its gas pipeline system.

The Safety Board concludes that plastic pipe extruded by Century Utility Products, Inc., and made from Union Carbide's DHDA 2077 Tan resin has poor resistance to brittle-like cracking under stress intensification, and this characteristic contributed to the Waterloo, Iowa, accident.

The Safety Board believes that RSPA should notify pipeline system operators who have installed polyethylene gas piping extruded by Century Utility Products, Inc., from Union Carbide Corporation DHDA 2077 Tan resin of the piping's poor brittle-crack resistance. The Safety Board further believes that RSPA should require these operators to develop a plan to closely monitor the performance of this piping and to identify and replace, in a timely manner, any of the piping that indicates poor performance based on such evaluation factors as installation, operating, and environmental conditions; piping failure characteristics; and leak history.

Strength Downturn and Brittle Characteristics

While Century piping has been identified specifically as being subject to brittle-like cracking (slow crack growth), evidence suggests that much of the early polyethylene piping, depending on the brands, may be more susceptible to such cracking than originally thought and thus may also be subject to premature failure.

The principal process used in the United States to rate the strength of plastic piping materials has been, and remains, the procedure this report has referred to as the PPI procedure. The PPI procedure, which was developed in the early 1960s, involved subjecting test piping to different stress values and recording how much time elapsed before the piping ruptured. The resulting data were then plotted, and a best-fit straight line was derived to represent the material's decline in rupture resistance as its time under stress increased.

To meet the requirements of the PPI procedure, at least one tested sample had to be able to withstand some level of hoop stress without rupturing for at least 10,000 hours, or slightly more than 1 year. The straight line plotted describing the data for this material was extrapolated out by a factor of 10, to 100,000 hours (about 11 years). The point at which the sloping straight line intersected the 100,000-hour point indicated the appropriate hydrostatic design basis for this material.

A key assumption characterized the assignment of a hydrostatic design basis under the PPI procedure: The procedure assumed that the gradual decline in the strength of plastic piping material as it was subjected to stress over time would always be described by a straight line. In the early 1960s, the industry had had little long-term experience with plastic piping, and a straight line seemed to represent the response of the material to laboratory stress testing. With little other information on which to base strength estimations, the straight-line assumption appeared valid.

As experience grew with plastic piping materials and as better testing methods were developed, however, the straight-line assumptions of the PPI procedure came to be challenged. Elevated-temperature testing indicated that polyethylene piping can exhibit a decline in strength that does not follow a straight line path but instead describes a downturn, as shown in figure 9. The difference between the actual (falloff) and projected (straight line) strengths became even more pronounced as the lines were extrapolated beyond 100,000 hours. The timing and slope of the downturn varied by pipe formulation and manufacturer.

Piping manufacturers addressed this issue by improving their formulations to delay onset of the downturn in strength. At the same time, the PPI procedure was improved to reflect the fact that elevated-temperature testing, by accelerating the fracture process, provided a good representation of the true long-term strength of the tested material at 73 °F. By 1986, the PPI adopted a requirement to exclude any materials that deviated from the straight-line path to at least 100,000 hours at 73 °F.

The combination of more durable modern plastic piping materials and more realistic strength testing has rendered the strength ratings of modern plastic piping much more reliable. Unfortunately, much of the early plastic piping was sold and installed with expectations of strength and long-term performance that, because they were based on questionable assumptions about long-term performance, may not have been valid. This is borne out by data from a variety of sources. The history of strength rating requirements, a review of the piping properties and literature, and observations of several experts with extensive experience in plastic piping, all suggest that much of the polyethylene pipe, depending upon the brands, manufactured from the 1960s through the early 1980s fails at lower stresses and after less time than originally projected. The Safety Board therefore concludes that the procedure used in the United States to rate the strength of plastic pipe may have overrated the strength and resistance to brittle-like cracking of much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s.

Another important assumption of the design protocol for plastic pipe involved the ductility of the materials. It was assumed, based on short-term tests, that plastic piping had long-term ductile properties. Ductile material, by bending, expanding, or flexing, can redistribute stress concentrations better than can brittle material, such as cast iron. Notable from results of tests performed under the PPI procedure was that those short-term stress ruptures in the testing process tended to be characterized by substantial material deformation in the area of the rupture. This deformation described a material with obvious ductile properties. Under prolonged testing, however, as time-to-failure increased, some stress ruptures in some materials occurred as slit failures that, because they were not accompanied by substantial deformation, were more typical of brittle-like failures. These slit or brittle-like failures were characterized by crack initiation and slow crack growth. The PPI procedure did not distinguish between ductile fractures and slit fractures and assumed that both failures would be described by the same straight line.

The assumption of ductility of plastic piping had important safety ramifications. For example, a number of experts believed it was safe to design plastic piping installations based on stresses primarily generated by internal pressure and to give less consideration to stress intensification generated by external loading. Ductile material reduces stress intensification by localized yielding, or deformation.

As noted previously, laboratory data supported the strength rating assigned to DHDA 2077 Tan resin by the process used at the time to rate strength; nevertheless, the material showed evidence of early ductile-to-brittle transition. The fact that the process used to measure the long-term durability of piping materials did not reveal the premature susceptibility to brittle-like cracking of the DHDA 2077 Tan material highlights the weaknesses of the process in use at the time. More significantly, it calls into question the durability of other early materials that were rated using the same process and that remain in service today. This concern is heightened by the fact that, in addition to the Waterloo accident involving Century pipe and DHDA 2077 Tan resin, numerous other accidents investigated or documented by the Safety Board have suggested that brittle-like cracking occurs in older plastic piping at significant rates.

Stress intensification has been an element common to many plastic gas pipeline accidents investigated by the Safety Board. The premature transition of plastic piping from ductile failures to brittle failures appears to have little observable adverse impact on the serviceability of plastic piping except in those instances in which the piping is subjected to external stresses. Rock impingement, soil settlement, and excess pipe bending are among the potential sources of stress intensification, and the combination of brittle piping and external stresses can lead to significant rates of failures. These failures can, in turn, lead to serious accidents. The Safety Board therefore concludes that much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s may be susceptible to premature brittle-like failures when subjected to stress intensification, and these failures represent a potential public safety hazard.

The Safety Board believes that RSPA should determine the extent of the susceptibility to premature brittle-like cracking of older plastic piping (beyond that piping marketed by Century Utility Products, Inc.) that remains in use for gas service nationwide. RSPA should then inform gas system operators of the findings and require them to closely monitor the performance of the older plastic piping and to identify and replace, in a timely manner, any of the piping that indicates poor performance based on such evaluation factors as installation, operating, and environmental conditions; piping failure characteristics; and leak history. Because materials other than polyethylene have been used in plastic pipe for gas service, and even though the Safety Board has not examined those materials in depth, RSPA would do well to address those other plastic piping materials still in gas service.

The Safety Board further believes that RSPA should immediately notify those States and territories with gas pipeline safety programs of the susceptibility to premature brittle-like cracking of much of the plastic piping manufactured from the1960s through the early 1980s and of the actions that RSPA will require of gas system operators to monitor and replace piping that indicates unacceptable performance.

Information Dissemination Within the Gas Industry

As noted earlier, much of the polyethylene pipe, depending upon the brands, from the 1960s through the early 1980s may be susceptible to premature brittle-like failures when subjected to stress intensification. Poor resistance to crack initiation and slow crack growth in the face of stress intensification can translate into a higher incidence of leaks and a decrease in public safety.

Premature brittle-like cracking in plastic piping is a complex phenomenon. Those pipelines operators who wish to study the phenomenon can gain a basic understanding of brittle-like cracking by researching the technical literature, but without direct and straightforward communication to pipeline operators about brands of piping and conditions that increase the likelihood of brittle cracking, many pipeline operators may not have the knowledge to make good decisions affecting public safety. Some of these key decisions include how often to conduct leak surveys and whether to repair or replace portions of pipeline systems.

Frequently, piping manufacturers, because they can receive feedback from a number of customers, are the first to learn of systemic problems with their products. For small operators, contact with a manufacturer may be the major source of outside communication about poorly performing products. Unfortunately, while manufacturers have a high degree of technical expertise regarding their products, they may also tend to aggressively publicize the best performance characteristics of their products while only reluctantly acknowledging weaknesses. The Safety Board is aware of only a very few cases in which manufacturers of resin or pipe have formally notified the gas industry of materials having poor resistance to brittle cracking.

Thus, although reputable manufacturers commonly provide essential technical assistance and serve as partners to pipeline operators, operators are still responsible for evaluating and determining which products are most likely to maintain the integrity of their pipeline systems. Furthermore, perhaps because the possibility of premature failure of plastic piping due to brittle-like cracking has not been fully appreciated within the industry and the scope of the potential problem has not been fully measured, the Federal Government has not provided information on this issue to gas system operators. The Safety Board concludes that gas pipeline operators have had insufficient notification that much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s may be susceptible to brittle-like cracking and therefore may not have implemented adequate pipeline surveillance and replacement programs for their older piping.

In the view of the Safety Board, manufacturers of resin and pipe should do more to notify pipeline operators about the poor brittle-crack resistance of some of their past products. The PPI is the manufacturers' organization that covers most of the major resin and pipe producers, many of whom have manufactured resin and pipe for several years. Although manufacturers of some of the worst performing materials and piping products may not have survived and therefore may not be current members of the PPI, the current members of the PPI have produced much, if not most, of the plastic piping and materials used in the manufacture of plastic piping over many years. The Safety Board therefore believes that the PPI should advise its members to notify pipeline system operators if any of their piping products, or materials used in the manufacture of piping products, currently in service for natural gas or other hazardous materials indicate poor resistance to brittle-like failure.

In the interest of public safety and in order for the Federal Government to fully exercise its oversight responsibilities, the Safety Board believes that RSPA should, in cooperation with the manufacturers of products used in the transportation of gases or liquids regulated by the OPS, develop a mechanism by which the OPS will receive copies of all safety-related notices, bulletins, and other communications regarding any defect, unintended deviation from design specification, or failure to meet expected performance of any piping or piping product that is now in use or that may be expected to be in use for the transport of hazardous materials.

Over a number of years, the GRI has developed a significant amount of data on older plastic piping, but it has published the data in codified terms. Without a way to associate codes with specific products, the average gas pipeline operator could not make effective use of the data. The Safety Board concludes that, even though the GRI has developed a significant amount of data about older plastic piping used for gas service, because the data have been published in codified terms, the information is not sufficiently useful to gas pipeline system operators. The Safety Board believes that the GRI should publish the codes used to identify plastic piping products in previous GRI studies to make the information contained in these studies more useful to pipeline system operators.

Installation Standards and Practices

Because of the large safety factor[80] used in the design equation, even many of the materials

[80] Technically, this term should be "design factor."

having early downturns in strength appear, absent stress intensification, to have the capacity to provide good service. Unfortunately, stress intensification, which can take many forms, has been found in a number of gas piping systems.

Almost all of the plastic pipeline accidents the Safety Board has investigated involving brittle-like cracking have been linked to stress intensification generated by external forces acting on the pipe. Examples of conditions that can generate stress intensification include differential earth settlement, particularly at connections with more rigidly anchored fittings; excessive bending as a result of installation configurations, especially at fittings; and point contact with rocks or other objects.

As discussed below, much of the guidance available to gas system operators for limiting stress intensification at plastic pipeline connections to steel mains is inadequate or ambiguous. It is particularly significant that none of the steel tapping tee manufacturers had published recommendations to safely limit shear and bending forces at connections where their products are used. Based on its review of this guidance and on the history of the plastic pipeline accidents it has investigated, the Safety Board concludes that, because guidance covering the installation of plastic piping is inadequate for limiting stress intensification at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces. The specific limitations of existing guidance are addressed in the sections that follow.

Federal Regulations -- RSPA acknowledges that the regulation that requires gas service lines to be installed so as to minimize anticipated piping strain and external loading lacks performance measurement criteria. The Safety Board pointed out in a previous accident investigation report[81] that, although the OPS considers many of its pipeline safety regulations to be performance-oriented requirements, many are no more than general statements of required actions that do not establish any criteria against which the adequacy of the actions taken can be evaluated. The Safety Board has further stated that regulations that do not contain measurable standards for performance make it difficult to determine compliance with the requirements. The Safety Board therefore previously recommended that RSPA:

> P-90-15
> Evaluate each of its pipeline safety regulations to identify those that do not contain explicit objectives and criteria against which accomplishment of the objective can be measured; to the extent practical, revise those that are so identified.

As a result of this safety recommendation, the OPS asked the National Association of Pipeline Safety Representatives liaison committee to review the 20 regulations deemed to be the least enforceable due to lack of clarity. The Safety Board has encouraged RSPA to make such a review a periodic effort so that all of the regulations, not just the specified 20, are continually clarified. The last correspondence to the Safety Board from the OPS regarding this recommendation was on March 8, 1993, and the recommendation has remained classified "Open--Acceptable Response." In an October 31, 1997, letter to the OPS, the Safety Board inquired as to the status of 28 open safety recommendations to RSPA, including P-90-15. The OPS has not yet provided a written response to the request for the status of P-90-15. The Safety Board will continue to follow the progress and urge completion of this recommendation. In the meantime, other elements of the gas pipeline industry can take steps to enhance the protection of vulnerable piping at connections, as outlined below.

A.G.A. Plastic Pipe Manual for Gas Service -- A protective sleeve helps to shield the pipe at the connection point from bearing loads and shear forces, and controls the maximum bending. The *A.G.A. Plastic Pipe Manual for Gas Service* recommends installing protective sleeves at connections of plastic pipe, but it does not directly address designing the sleeve to have the correct inner diameter and length, or the need to position the sleeve

[81] National Transportation Safety Board Pipeline Accident Report--*Kansas Power and Light Company Natural Gas Pipeline Accidents, September 16, 1988, to March 29, 1989* (NTSB/PAR-90/03).

properly. Instead, it includes a sentence recommending that manufacturers' instructions be followed carefully. Such advice presumes that the manufacturers' instructions address designing the sleeve to have the correct inner diameter and length, as well as positioning the sleeve properly, in order to limit the shear and bending forces at the connection. Unfortunately, since none of the steel tapping tee manufacturers recommend any precautions to limit shear and bending forces at the connection point, gas pipeline operators may not realize the importance of determining these parameters.

The *A.G.A. Plastic Pipe Manual for Gas Service* does not provide an explanation for the following sentence:

> Installation of the tee outlet at angles up to 45° from the vertical or along the axis of the main as a 'side saddle' or 'swing joint' may be considered to further minimize...stresses.

This sentence is subject to different interpretations and does not explain how stresses might be reduced. Moreover, many gas system pipeline operators recognize that installing services 90° from the main helps with future locating of the pipe and reduces the likelihood of excessive bending, which could generate excessive stress. In the view of the Safety Board, this sentence does not provide useful guidance as it is written, and the A.G.A. Plastic Materials Committee would be well advised to either expand on or delete this sentence.

A.G.A. Gas Engineering and Operating Practices Series -- Illustrations from the GEOP series show protective sleeves extending to undisturbed or compacted soil or to blocking. But these figures show the blocking positioned so that, under some conditions, either the edge of the blocking or the edge of the protective sleeve might provide a fixed contact point on the service pipe. The Safety Board notes that B31.8 and ASTM D2774 discourage supporting plastic pipe by the use of blocking. In the view of the Safety Board, these illustrations would provide better guidance if they were revised to eliminate showing the possibility of blocking or other fixed contact point supporting plastic pipe.

The Safety Board believes that the A.G.A. should revise its *Plastic Pipe Manual for Gas Service* and the *Gas Engineering and Operating Practices* series to provide complete and unambiguous guidance for limiting stress at plastic pipe service connections to steel mains.

GPTC Guide for Gas Transmission and Distribution Piping Systems -- The Safety Board has previously noted that a protective sleeve's correct inner diameter and length are important to protect the piping from excessive forces. The Safety Board even issued a safety recommendation that the GPTC Guide be modified accordingly. As a result of this safety recommendation, the GPTC Guide now includes guidance under 49 CFR 192.361 to install protective sleeves "designed for the specific connection...to reduce stress concentrations." Designing protective sleeves for the specific connection is presumed to include designing the sleeve for the correct inner diameter and length, and may also include positioning the sleeve correctly, since positioning the sleeve affects its effective length. However, if steel tapping tee manufacturers do not address the parameters for sleeve design and positioning, gas pipeline operators may not realize the importance of determining these parameters. The guidance would be much more useful to gas pipeline operators if the GPTC included in the guide a specific statement of the need to design protective sleeves so that they will have the correct inner diameter and length, as well as the need to properly position the sleeves.

Although the guide references the *A.G.A. Plastic Pipe Manual for Gas Service* in various locations, and this manual provides recommendations on bending limits, the guide does not reference this manual under the guide material under 49 CFR 192.361. Therefore, the Safety Board believes that the GPTC should revise the guide to include complete guidance for the proper installation of plastic service pipe connections to steel mains. The guidance should emphasize the need to limit pipe bending and should include a discussion of the proper design and positioning of a protective sleeve to limit stress at the connection.

ASTM -- ASTM D2774 recommends the use of a protective sleeve, if needed to protect against possible differential settlement. The standard practice additionally advises consultation with manufacturers, which would presumably address designing the sleeve with a proper diameter and length, as well as positioning the sleeve correctly. However, as noted previously, none of the steel tapping tee manufacturers has recommended precautions to limit stresses at the service to main connection; therefore, gas pipeline operators may not realize the importance of determining these parameters. Consequently, the Safety Board believes that the ASTM should revise ASTM D2774 to emphasize that a protective sleeve, in order to be effective, must be of the proper length and inner diameter for the particular connection and must be positioned properly.

Currently, manufacturers that provide protective sleeves have their own criteria for sleeve lengths and diameters. Some manufacturers' criteria are based on limiting stress to a maximum safe value,[82] while one manufacturer has advised the Safety Board that its sleeve is not designed to limit bending but only to guard against shear forces at the connection point. A published common criteria would better motivate a wider spectrum of manufacturers and gas operators to apply scientific reasoning to their decisions on protective sleeve use. A published common criteria would additionally provide guidance to gas operators who provide their own sleeves rather than using manufacturer-supplied sleeves. The Safety Board therefore believes that the ASTM should develop and publish standard criteria for the design of protective sleeves to limit stress intensification at plastic pipeline connections.

Guidance Manual for Operators of Small Natural Gas Systems -- The expressed purpose of RSPA's *Guidance Manual for Operators of Small Natural Gas Systems* is to assist nontechnically trained persons who operate small gas systems. However, the manual provides no caution against bending close to a plastic service connection to a steel main. The manual recommends following manufacturers' instructions and indicates that a properly designed sleeve should be used at this connection, which would address designing the sleeve with the proper diameter and length. However, as noted previously, none of the steel tapping tee manufacturers has recommended precautions to limit stresses at the service to main connection; therefore, nontechnically trained persons may not realize the importance of determining these parameters.

Because manufacturers' recommendations in the above areas are also currently inadequate, the Safety Board believes that RSPA should revise its *Guidance Manual for Operators of Small Natural Gas Systems* to include more complete guidance for the proper installation of plastic service pipe connections to steel mains. The guidance should address pipe bending limits and should emphasize that a protective sleeve, in order to be effective, must be of the proper length and inner diameter for the particular connection and must be positioned properly.

Manufacturers' Recommendations -- Reliance on manufacturers' recommendations is a common theme running through many of the primary published sources of industry guidance for limiting stress intensification on plastic piping. CSR PolyPipe was relatively new to providing polyethylene pipe to the gas market. When CSR PolyPipe entered the market, the three other major polyethylene piping manufacturers had already published installation recommendations to limit stress intensification, and plastic materials were vastly improved compared to earlier versions with respect to resistance to crack initiation and slow crack growth. CSR PolyPipe therefore saw less need to develop extensive recommendations. And although CSR PolyPipe does not manufacture steel tapping tees with compression ends for attachment to plastic services, it does manufacture the pipe that will be attached to steel tapping tees via mechanical compression couplings. To facilitate the safe use of plastic piping, the Safety Board believes that the PPI, of which all four of the major piping producers are members, should advise its plastic pipe manufacturing members to develop and publish recommendations for limiting shear and bending forces at plastic service pipe connections to steel mains.

[82] Allman, W. B., "Determination of Stresses and Structural Performance in Polyethylene Gas Pipe and Socket Fittings Due to Internal Pressure and External Soil Loads," *1975 Operating Section Proceedings*, American Gas Association, 1975.

Compared to plastic piping manufacturers, steel tapping tee manufacturers may have much less technical expertise regarding the strength and failure modes of plastic pipe; however, steel tapping tee manufacturers, who have designed their rigid steel tees to connect to flexible plastic gas pipe, have a responsibility to provide recommendations for the safe use of their products. If a steel tee manufacturer believes that installation options are dependent on the type of plastic to be connected and that these options can be addressed only by the pipe manufacturer, the tee manufacturer has a responsibility to state that in its literature and to provide the gas system operator with direction for best using its product safely.

The Safety Board therefore believes that Continental, Dresser, Inner-Tite, and Mueller should develop and publish detailed recommendations and instructions for limiting shear and bending forces at locations where their steel tapping tees are used to connect service pipe to steel mains. While gas system operators have the option of not accepting manufacturers' recommendations, many gas system operators rely on manufacturers to provide installation recommendations for the safe use of their products. With published recommendations, gas system operators may be far less likely to overlook prudent construction practices, such as providing proper compaction and support, limiting bends, and using protective sleeves. Tee manufacturers may wish to make these published recommendations even more effective by packaging them with each tee shipped, thus ensuring that the gas operator or the tee installer, or both, will have ready access to them.

A Continental representative told the Safety Board that the protective sleeve it provides to customers as an option does not provide sufficient clearance to allow field wrap to be applied to the metallic portion under the sleeve as a way to prevent corrosion. The Safety Board concludes that the use of Continental tapping tees with Continental protective sleeves may leave the tapping tees susceptible to corrosion because the sleeves do not provide sufficient clearance for the application of field wrap to the metallic steel tapping tee. The Safety Board therefore believes that Continental should provide a means to ensure that use of Continental-designed protective sleeves with the company's steel tapping tees at plastic pipe connections to steel mains does not compromise corrosion protection for the connection.

Installation Issues at Site of Waterloo Accident -- Safety Board examination of the fracture surface and the failed pipe from the Waterloo accident revealed evidence of stress intensification. For example, the upper portion of the inside of the pipe showed the impression of the edge of the tee stiffener, indicating that the top of the pipe had been pressed down. The failure of the pipe can be directly associated with this stressed area, which was characterized by several brittle-like slow crack growth fractures that originated on or near the pipe inner wall just outside the depression associated with the tip of the tee stiffener. These slow crack fractures propagated through the wall of the pipe.

The stress intensification noted in the Waterloo pipe was consistent with the pipe's having been subjected to shear and bending forces generated primarily by soil settlement.[83] Soil settlement is a common source of stress intensification for buried plastic pipelines, and it can occur and contribute to a piping failure even though no observable voids are noted during a subsequent excavation. Ultimate settlement of backfill can take many years, and sometimes it only occurs after periods of heavy rains (such as the area experienced the previous year) or under additional external loading (such as that represented by truck traffic over the connection).

The accident investigation could not determine whether the ground settlement at Waterloo occurred because of inadequate compaction and support under the connection at the time it was installed, or whether it occurred despite initial adequate compaction and support. Nor could it be conclusively determined whether the amount of soil settlement was slight and generated relatively low stresses over a long

[83]The failed pipe also showed signs that the installed horizontal curve may have generated horizontal bending forces. Other factors contributing to stress at the connection included the pipe's internal pressure and may have included residual stresses inside the wall of the pipe resulting from the manufacturing process.

period of time, or whether the soil settlement was substantial and generated relatively high stresses over a relatively short period of time. Because of these uncertainties, investigators could not determine how much more resistance to crack initiation and slow crack growth the pipe would have needed to have successfully resisted the stresses to which it was subjected.

MidAmerican Energy, at the time of this accident investigation, had no installation standard that called for firm compacted support under plastic service connection points to steel mains. MidAmerican Energy connected plastic service pipe to mains via factory-joined plastic-to-steel transition fittings. As noted previously, the manufacturers for these specialty fittings, unlike steel tapping tee manufacturers, have protective sleeves available. Although MidAmerican Energy designed its own protective sleeves for this application, it did so without a design criteria for length or inner diameter, or for positioning the protective sleeves. Without such criteria, MidAmerican Energy may reduce the sleeve's effectiveness in limiting stress intensification. The Safety Board concludes that, because MidAmerican Energy's gas construction standards do not establish well-defined criteria for supporting plastic pipe connections to steel mains or for designing or installing its protective sleeves at these connections, these standards do not ensure that connections will be adequately protected from stress intensification. The Safety Board believes that MidAmerican Energy should modify its gas construction standards to require (1) firm compacted support under plastic service connections to steel mains, and (2) the proper design and positioning of protective sleeves at these connections.

The service involved in the Waterloo accident was installed with a horizontal bend that was sharper than that recommended by current gas industry guidance recommendations; however, the bend may have been installed in the direction of the residual coil bend. Gas industry recommendations do not address residual bending in the pipe, even though plastic piping is often delivered to job sites in banded coils, which leaves some residual bending in the piping even after the bands are removed. Installing coiled pipe with any necessary bending in the direction of the residual bend may be a good practice to limit stresses. Conversely, bending pipe against the direction of the residual coil bend, even if the resulting bend is in accordance with gas industry recommendations, will induce greater stresses.

Plastic piping manufacturers continue to have the best combination of technical expertise and practical knowledge for determining bend radius recommendations. Therefore, the Safety Board believes that the PPI should advise its plastic pipe manufacturing members to revise their pipeline bend radius recommendations as necessary to take into account the effects of residual coil bends in plastic piping.

Gas System Performance Monitoring

Federal regulations require that gas pipeline system operators have in place an ongoing program to monitor the performance of their piping systems. Before the Waterloo accident, Midwest Gas developed only a limited capability for monitoring and analyzing the condition of its gas system. For example, the company did not statistically correlate failure rates to the amounts of installed pipe provided by specific manufacturers. The design of the program meant that the relatively few areas with high failure rates (for example, those with Century pipe) were aggregated with and therefore masked by the large number of plastic piping installations that had low failure rates. Thus, the Midwest Gas surveillance program did not reveal the high failure rates associated with Century pipe. Only after the accident did Midwest Gas identify the Century pipe within its pipeline system as having high failure rates, even though the company could have collected and processed the same type of data and reached the same determination before the accident. If Midwest Gas had further correlated its data to years of installation, it may have also been able to examine the effects of its changing installation methods or changes in performance with different manufacturers through the years.

The Safety Board concludes that, before the Waterloo accident, the systems used by Midwest Gas Company for tracking, identifying, and statistically characterizing plastic piping failures did not permit an effective analysis of system failures and leakage history. The Safety Board further concludes that if, before the Waterloo accident, Midwest Gas had had an effective surveillance program that tracked and identified the high leakage rates associated with Century piping when subjected to stress intensification, the company could have implemented a replacement program for the pipe and may have replaced the failed service connection before the accident.

Since the accident, MidAmerican Energy has revised its systems, adding parameters to provide the company with added capability to sort failures. However, MidAmerican Energy has not chosen parameters that will allow an adequate analysis of its plastic piping system failures and leakage history. For example, the generic "improper installation" is a parameter to be linked to leaks; however, no parameters have been added for the presence, lack, improper design, or improper placement of a protective sleeve. And no parameters have been added to link leaks to squeeze locations, improper joining, or items to differentiate between insufficient support and excessive installed bending. The Safety Board therefore concludes that MidAmerican Energy's current systems for tracking, identifying, and statistically characterizing plastic piping failures do not enable an effective analysis of system failures and leakage history.

The Safety Board believes that MidAmerican Energy should, as a basis for the timely replacement of its plastic piping systems that indicate unacceptable performance, review its existing plastic piping surveillance and analysis program and make the changes necessary to ensure that the program is based on sufficiently precise factors such as piping manufacturer, installation date, pipe diameter, geographical location, and conditions and locations of failures.

An effective surveillance program would include the data base inputs that would allow the company to adequately monitor and characterize the types and causes of plastic piping field failures. The *A.G.A. Plastic Pipe Manual for Gas Service* recommends the use of a form for recording necessary information on plastic piping failures; this form may be helpful to MidAmerican Energy as it decides which data fields would be necessary to provide for an adequate analysis of its plastic piping system failures and leakage history. The *A.G.A. Plastic Pipe Manual for Gas Service* further recommends collecting this information, then performing visual examinations of the type and cause of failure and, in some instances, a laboratory analysis. The above steps may help MidAmerican Energy comprehensively monitor and address parts of its plastic pipeline system—other than those installations with Century pipe—that may also indicate unacceptable performance.

In a previous accident investigation report,[84] the Safety Board pointed out that many operators had not established procedures to comply with Federal regulations requiring surveillance and investigation of failures. The Safety Board recommended that RSPA:

> <u>P-90-14</u>
> Emphasize, as a part of OPS inspections and during training and State monitoring programs, the actions expected of gas operators to comply with the continuing surveillance and failure investigation, including laboratory examination requirements.

In a letter to the Safety Board, RSPA responded that the TSI had increased emphasis on gas surveillance and failure investigation in the operations block of its industry seminars held across the country. The letter stated that the TSI would incorporate a discussion of accident analysis into a new hazardous liquids seminar that was to be presented for the first time in FY 1992. Additionally, RSPA noted that it planned to place additional emphasis on continuing surveillance and failure investigation requirements in its new inspection forms at the time of the next revision. Based on this response, the Safety Board classified Safety Recommendation P-90-14 "Closed—Acceptable Action."

Despite the RSPA response to this safety recommendation, for a variety of reasons—including the inadequate performance monitoring

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[84]National Transportation Safety Board Pipeline Accident Report--*Kansas Power and Light Company Natural Gas Pipeline Accidents, September 16, 1988, to March 29, 1989* (NTSB/PAR-90/03).

programs found at Midwest Gas/MidAmerican Energy, the susceptibility to brittle cracking of much of the polyethylene piping installed through the early 1980s, deficiencies noted in gas industry communications regarding poorly performing brands of polyethylene piping, and differences noted in the performance of different types and brands of polyethylene piping—RSPA may need to do more. Gas system operators may need to be advised once again of the importance of complying with Federal requirements for piping system surveillance and analyses. As is the case with older piping, an effective general pipeline surveillance program would be based on factors such as piping manufacturer, installation date, pipe diameter, operating pressure, leak history, geographical location, modes of failure (such as bending, inadequate support, rock impingement, or improper joining), location of failure (such as at the main to service or at pipe squeeze locations), and other factors such as the presence, absence, or misapplication of a sleeve. An effective program would also evaluate past piping and components installed, as well as past installation practices, to provide a basis for the replacement, in a planned, timely manner, of plastic piping systems that indicate unacceptable performance.

CONCLUSIONS

1. Plastic pipe extruded by Century Utility Products, Inc., and made from Union Carbide's DHDA 2077 Tan resin has poor resistance to brittle-like cracking under stress intensification, and this characteristic contributed to the Waterloo, Iowa, accident.

2. The procedure used in the United States to rate the strength of plastic pipe may have overrated the strength and resistance to brittle-like cracking of much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s.

3. Much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s may be susceptible to premature brittle-like failures when subjected to stress intensification, and these failures represent a potential public safety hazard.

4. Gas pipeline operators have had insufficient notification that much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s may be susceptible to brittle-like cracking and therefore may not have implemented adequate pipeline surveillance and replacement programs for their older piping.

5. Even though the Gas Research Institute has developed a significant amount of data about older plastic piping used for gas service, because the data have been published in codified terms, the information is not sufficiently useful to gas pipeline system operators.

6. Because guidance covering the installation of plastic piping is inadequate for limiting stress intensification at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces.

7. Because MidAmerican Energy Corporation's gas construction standards do not establish well-defined criteria for supporting plastic pipe connections to steel mains or for designing or installing its protective sleeves at these connections, these standards do not ensure that connections will be adequately protected from stress intensification.

8. Before the Waterloo, Iowa, accident, the systems used by Midwest Gas Company for tracking, identifying, and statistically characterizing plastic piping failures did not permit an effective analysis of system failures and leakage history.

9. If, before the Waterloo accident, Midwest Gas Company had had an effective surveillance program that tracked and identified the high leakage rates associated with Century Utility Products, Inc., piping when subjected to stress intensification, the company could have implemented a replacement program for the pipe and may have replaced the failed service connection before the accident.

10. MidAmerican Energy Corporation's current systems for tracking, identifying, and statistically characterizing plastic piping failures do not enable an effective analysis of system failures and leakage history.

11. The use of Continental Industries, Inc., tapping tees with the company's protective sleeves may leave the tapping tees susceptible to corrosion because the sleeves do not provide sufficient clearance for the application of field wrap to the metallic steel tapping tee.

RECOMMENDATIONS

As a result of this special investigation, the National Transportation Safety Board makes the following safety recommendations:

--to the Research and Special Programs Administration:

Notify pipeline system operators who have installed polyethylene gas piping extruded by Century Utility Products, Inc., from Union Carbide Corporation DHDA 2077 Tan resin of the piping's poor brittle-crack resistance. Require these operators to develop a plan to closely monitor the performance of this piping and to identify and replace, in a timely manner, any of the piping that indicates poor performance based on such evaluation factors as installation, operating, and environmental conditions; piping failure characteristics; and leak history. (P-98-1)

Determine the extent of the susceptibility to premature brittle-like cracking of older plastic piping (beyond that piping marketed by Century Utility Products, Inc.) that remains in use for gas service nationwide. Inform gas system operators of the findings and require them to closely monitor the performance of the older plastic piping and to identify and replace, in a timely manner, any of the piping that indicates poor performance based on such evaluation factors as installation, operating, and environmental conditions; piping failure characteristics; and leak history. (P-98-2)

Immediately notify those States and territories with gas pipeline safety programs of the susceptibility to premature brittle-like cracking of much of the plastic piping manufactured from the 1960s through the early 1980s and of the actions that the Research and Special Programs Administration will require of gas system operators to monitor and replace piping that indicates unacceptable performance. (P-98-3)

In cooperation with the manufacturers of products used in the transportation of gases or liquids regulated by the Office of Pipeline Safety, develop a mechanism by which the Office of Pipeline Safety will receive copies of all safety-related notices, bulletins, and other communications regarding any defect, unintended deviation from design specification, or failure to meet expected performance of any piping or piping product that is now in use or that may be expected to be in use for the transport of hazardous materials. (P-98-4)

Revise the *Guidance Manual for Operators of Small Natural Gas Systems* to include more complete guidance for the proper installation of plastic service pipe connections to steel mains. The guidance should address pipe bending limits and should emphasize that a protective sleeve, in order to be effective, must be of the proper length and inner diameter for the particular connection and must be positioned properly. (P-98-5)

--to the Gas Research Institute:

Publish the codes used to identify plastic piping products in previous Gas Research Institute studies to make the information contained in these studies more useful to pipeline system operators. (P-98-6)

--to the Plastics Pipe Institute:

Advise your members to notify pipeline system operators if any of their piping products, or materials used in the manufacture of piping products, currently in service for natural gas or other hazardous materials indicate poor resistance to brittle-like failure. (P-98-7)

Advise your plastic pipe manufacturing members to develop and publish recommendations for limiting shear and bending forces at plastic service pipe connections to steel mains. (P-98-8)

Advise your plastic pipe manufacturing members to revise their pipeline bend radius recommendations as necessary to take into account the effects of residual coil bends in plastic piping. (P-98-9)

--to the Gas Piping Technology Committee:

Revise the *Guide for Gas Transmission and Distribution Piping Systems* to include complete guidance for the proper installation of plastic service pipe connections to steel mains. The guidance should emphasize the need to limit pipe bending and should include a discussion of the proper design and positioning of a protective sleeve to limit stress at the connection. (P-98-10)

--to the American Society for Testing and Materials:

Revise ASTM D2774 to emphasize that a protective sleeve, in order to be effective, must be of the proper length and inner diameter for the particular connection and must be positioned properly. (P-98-11)

Develop and publish standard criteria for the design of protective sleeves to limit stress intensification at plastic pipeline connections. (P-98-12)

--to the American Gas Association:

Revise your *Plastic Pipe Manual for Gas Service* and your *Gas Engineering and Operating Practices* series to provide complete and unambiguous guidance for limiting stress at plastic pipe service connections to steel mains. (P-98-13)

--to MidAmerican Energy Corporation:

Modify your gas construction standards to require (1) firm compacted support under plastic service connections to steel mains, and (2) the proper design and positioning of protective sleeves at these connections. (P-98-14)

As a basis for the timely replacement of your plastic piping systems that indicate unacceptable performance, review your existing plastic piping surveillance and analysis program and make the changes necessary to ensure that the program is based on sufficiently precise factors such as piping manufacturer, installation date, pipe diameter, geographical location, and conditions and locations of failures. (P-98-15)

--to Continental Industries, Inc.:

Provide a means to ensure that the use of your protective sleeves with your tapping tees at plastic pipe connections to steel mains does not compromise corrosion protection for the connection. (P-98-16)

--to Continental Industries, Inc. (P-98-17):

--to Dresser Industries, Inc. (P-98-18):

--to Inner-Tite Corporation (P-98-19):

--to Mueller Company (P-98-20):

Develop and publish recommendations and instructions for limiting shear and bending forces at locations where your steel tapping tees are used to connect plastic service pipe to steel mains.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

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April 23, 1998

National Transportation Safety Board

Washington, D.C. 20594

Pipeline Accident Brief

Pipeline Accident Number:	DCA-95-MP-001
Type of System:	Gas distribution
Accident Type:	Explosion and Fire
Location:	Waterloo, Iowa
Date and Time:	October 17, 1994; 10:07 a.m. local
Owner/Operator:	Midwest Gas Company[1]
Fatalities/Injuries:	Six fatalities and seven non-fatal injuries
Damage:	$250,000
Material Released:	Natural Gas
Pipeline Pressure:	25 pounds per square inch, gauge (psig)
Component Affected:	1/2-inch plastic pipe at steel tapping tee mechanical compression connection to steel main

The Accident

At 10:07 a.m. central daylight savings time on Monday, October 17, 1994, a natural gas explosion and fire destroyed a one-story, wood frame building in Waterloo, Iowa. The force of the explosion scattered debris over a 200-foot radius.

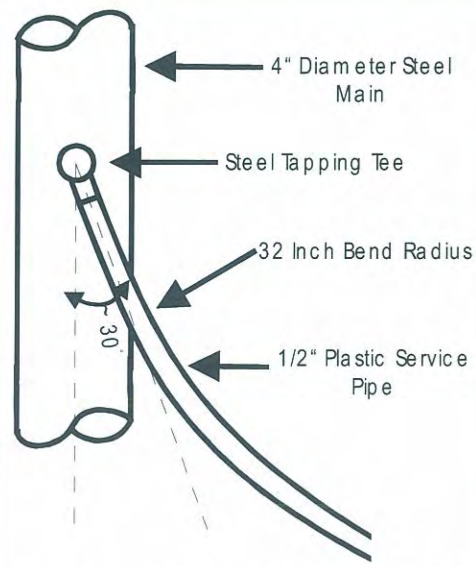
Six persons inside the building died, and one person sustained serious injuries. Three persons working in an adjacent building sustained minor injuries when a wall of the building collapsed inward from the force of the explosion. The explosion also damaged nine parked cars. A person in a vehicle who had just exited the adjacent building suffered minor injuries. Additionally, two firefighters sustained minor injuries during the emergency response. Two other nearby buildings also sustained structural damage and broken windows.

Site Information

The destroyed building was a neighborhood tavern known as Buzz's Bar. Adjacent to and east of the bar was Woodland Pattern Company, which was provided gas service by a 1/2-inch-diameter plastic polyethylene service pipeline. The service pipeline was installed by Iowa Public Service Company on September 3, 1971, and was operated at a maximum pressure of 25 psig.

[1]Because of a series of organizational changes and mergers, the name of the owner/operator of the gas system at Waterloo, Iowa, has changed over the years. In 1971, Iowa Public Service Company installed the gas service that ultimately failed. At the time of the accident, the gas system operator was known as Midwest Gas Company, while the current operator's name is MidAmerican Energy Corporation.

The underground pipeline connected with the steel gas main and entered the Woodland Pattern Company building between Buzz's Bar and the Woodland Pattern Company.



Service-to-main connection at site of Waterloo accident.

The area between Buzz's Bar and Woodland Pattern Company was unpaved and, according to those familiar with the location, was regularly used by beer trucks making deliveries to Buzz's Bar and by semitrailers delivering materials to Woodland Pattern Company. These trucks had been seen to drive over the area of the piping assembly that cracked. At various times, beer trucks servicing Buzz's Bar had been observed to park directly over the location of the pipe break. One witness stated that a beer delivery truck had been parked over the area of the pipe break at approximately 7:00 a.m. on the day of the accident.

Excavations following the accident uncovered a 4-inch-diameter steel main at a depth of about 3 feet. Welded to the top of the main was a steel tapping tee with markings indicating that the tee had been manufactured by Continental Industries, Inc. (Continental). Connected to the steel tee was a 1/2-inch-diameter plastic service pipe leading to Woodland Pattern Company. Markings on the plastic pipe indicated that it was a medium-density polyethylene material manufactured on June 11, 1970, in accordance with American Society for Testing and Materials (ASTM) standard D2513, and marketed by Century Utility Products, Inc. (Century). A circumferential crack through the plastic pipe was found at the tip of the tee's internal stiffener that protruded beyond the tee's coupling nut. A 1- to 2-foot-diameter "hard ball" surrounded the cracked pipe.[2]

Because Safety Board investigators did not arrive at the accident site until after excavation of the failed pipe, investigators had to consult several sources to determine the condition of the piping at the time of excavation. Photographs of the excavation, a Waterloo Fire Department video tape, and several witnesses all indicated that the downstream portion of the plastic pipe was found broken off and vertically displaced below the plastic pipe portion still attached to the steel tee. However, an Iowa State Fire Marshall's Office investigator, who directed and participated in the excavation, reported that the pipe was displaced by the excavation activities. That investigator also reported no observed voids in the soil under the failed assembly.

Service-to-main connection at site of Waterloo accident.

MidAmerican Energy estimated that the steel tee on the steel main was installed so that the polyethylene pipe exited the tee at an approximate 30° angle to the steel main. (See figure.)

[2]A "hard ball" is a term used in the gas industry for a soil condition where leaking natural gas over a period of time dries and hardens the soil adjacent to the leak.

The plastic service pipe leaving the tee immediately curved horizontally. After a portion of the pipe was taken to the laboratory for testing, the bend radius was measured at about 34 inches. Based on field conditions and photos, MidAmerican Energy has estimated the original installed horizontal bend radius to be approximately 32 inches.[3] This bend is sharper than currently recommended by industry guidelines for modern piping adjacent to fittings. However, a former Iowa Public Service Company employee stated that Iowa Public Service Company, in an effort to reduce the stress at the connection point, often attempted to install polyethylene services at an angle to the main to match the residual bend left after uncoiling the pipe.[4] This former employee stated that no set time was prescribed to allow for complete relaxing of the pipe, but that the pipe would be placed in the ditch, and the crews would weld the tee at what they judged to be the appropriate angle, in consideration of the natural bend of the pipe.

Also immediately from the tee outlet, the polyethylene bent downward. The tee outlet did not have a protective sleeve to reduce shear and bending forces at the connection.

Tests and Examination

Samples recovered from the plastic service line underwent several laboratory tests under the supervision of the Safety Board. Two of these tests were meant to roughly gauge the pipe's susceptibility to brittle-like cracking. These tests were a compressed ring environmental stress crack resistance (ESCR) test in accordance with ASTM F1248 and a notch tensile test known as a PENT test that is now ASTM F1473. Lower failure times in these tests indicate greater susceptibility to brittle-like cracking under test conditions. The ESCR testing of 10 samples from the pipe yielded a mean failure time of 1.5 hours, and the PENT testing of 2 samples yielded failure times of 0.6 and 0.7 hours. Test values this low have been associated with materials having poor performance histories[5] characterized by high leakage rates at points of stress intensification due to crack initiation and slow crack growth typical of brittle-like cracking.

To facilitate identification, the fracture surfaces were divided into two regions, A and B, around the circumference of the failed pipe. If a cross section of the pipe, looking toward the tee, were superimposed on a clock face, region A would extend from approximately the 9:00 position up across the top and down to about 1:30, with the center of the region at about 11:15. Region B took up the remainder of the pipe surface, extending from about the 1:30 position down across the bottom and up to 9:00.

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[3]Polyethylene pipe installed with a bend often, over time, permanently deforms in the direction of the bend. This permanent deformation partially reduces the stresses generated by the bending forces. When the pipe is released from its installation configuration, the pipe can straighten to some extent.

[4]MidAmerican Energy has indicated that Iowa Public Service's plastic service pipe was received in coils from Century. After uncoiling the pipe, some residual bending remains. The amount of residual bending depends on the factory coiling conditions.

[5]Uralil, F. S., et al., *The Development of Improved Plastic Piping Materials and Systems for Fuel Gas Distribution—Effects of Loads on the Structural and Fracture Behavior of Polyolefin Gas Piping*, Gas Research Institute Topical Report, 1/75 - 6/80, NTIS No. PB82-180654, GRI Report No. 80/0045, 1981, and Hulbert, L. E., Cassady, M. J., Leis, B. N., Skidmore, A., *Field Failure Reference Catalog for Polyethylene Gas Piping, Addendum No. 1*, Gas Research Institute Report No. 84/0235.2, 1989, and Brown, N. and Lu, X., "Controlling the Quality of PE Gas Piping Systems by Controlling the Quality of the Resin," *Proceedings Thirteenth International Plastic Fuel Gas Pipe Symposium*, pp 327-338, American Gas Association, Gas Research Institute, Battelle Columbus Laboratories, 1993.

The fracture in region A was located immediately outside the tee's internal stiffener. The crack was perpendicular to the pipe wall and directly in line with the end of the tee's internal stiffener. The inside surface of the pipe throughout region A was characterized by a circumferential impression from the tip of the tee's stiffener. A similar impression was not found in region B. This impression was only found on the pipe segment that was still attached to the steel tee, and was not evident on any part of the pipe segment that was detached from the steel tee. Region A was characterized by several brittle-like slow crack growth fractures, each of which initiated on or near the pipe inner wall just outside the depression associated with the tip of the tapping tee's stiffener. These slow crack fractures propagated on almost parallel planes slightly offset from each other through the wall of the pipe. As the cracks from different planes continued to grow and began to overlap one another, ductile tearing occurred between the planes, which produced a jagged appearance in parts of the overall circumferential crack in region A Thus, even though substantial deformation was observed in part of the fracture, the initiating cracks were still classified as brittle-like.

Region B contained two brittle-like crack growth sections that initiated from each end of region A. Cracks from each end of region A propagated through region B on approximate 45° planes towards the tee (partially exposing the tee's stiffener) and met at the bottom (the 6:00 position). The remaining ligament tore with visible deformation at the bottom.

Laboratory comparisons showed that the fractures that initiated and grew in region A were consistent with fractures generated by long-term shear and bending forces at the end of the stiffener. The fractures in region B were consistent with a continuation of the same loading system described for region A but occurred subsequent to those in region A. The last ligament that fractured at the 6:00 position in region B was consistent with ductile tearing. Examination could not determine whether the last remaining ligament tore because of concentrated stresses prior to the excavation or because of excavation activities after the accident.

Other Information

Flooding was reported in the area during the summer of 1993. Midwest Gas's most recent leak surveys, performed in March 1994, did not detect a leak in this area. Records of odorant tests performed in September 1994 and on October 17, 1994 (two and a half hours after the accident), show odorant levels that met the level required by Federal standards.[6]

Probable Cause

The National Transportation Safety Board determines that the probable cause of the natural gas explosion and fire in Waterloo, Iowa, was stress intensification, primarily generated by soil settlement at a connection to a steel main, on a 1/2-inch polyethylene pipe that had poor resistance to brittle-like cracking.

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[6]Federal standards require the odorant in natural gas systems to be detectable at one-fifth of the lower explosive limit, which is typically at gas/air concentrations of 0.9 to 1.0 percent and above.

Organizations, Agencies, and Associations Referenced in this Report

American Gas Association (A.G.A.)
An organization dedicated to promoting and protecting the interests of its member natural gas local distribution companies. The A.G.A. has approximately 300 members, of which about 250 are natural gas local distribution companies.

American Society for Testing and Materials (ASTM)
An organization that provides a forum for producers, users, consumers, and others with a common interest, including representatives of government and academia, who come together to write standards for materials, products, systems, and services.

Gas Piping Technology Committee (GPTC)
An organization dedicated to the development of the *GPTC Guide for Gas Transmission and Distribution Piping Systems* (*GPTC Guide*). The purpose of the *GPTC Guide* is to provide assistance to gas pipeline system operators in complying with Federal regulations addressing the transportation of natural and other gases by pipeline.

Gas Research Institute (GRI)
A research, development, and commercialization organization dedicated to the interests of the natural gas industry. The organization's mission is to discover, develop, and deploy technologies and information that benefit gas customers and the industry.

Plastics Pipe Institute (PPI)
A manufacturers organization, the PPI is an operating unit of the Society of the Plastics Industry. Members of the PPI share a common interest in broadening market opportunities through the effective use of plastic piping in water and gas distribution, sewage and wastewater transport, oil and gas production, and in industrial, mining, power, communications, and irrigation applications.

Office of Pipeline Safety (OPS)
The Research and Special Programs Administration (see below) acts through the OPS to administer the U.S. Department of Transportation's national regulatory program to ensure the safe transportation of natural gas, petroleum, and other hazardous materials by pipeline. The OPS develops regulations and other mechanisms to ensure safety in design, construction, testing, operation, maintenance, and emergency response of pipeline facilities.

Research and Special Programs Administration (RSPA)
A part of the U.S. Department of Transportation, RSPA has responsibility for emergency preparedness, research and technology, and transportation safety. The agency's safety mandate is to protect the Nation from the risks inherent in the transportation of hazardous materials by all transportation modes, including pipelines. RSPA carries out its pipeline safety and training programs through the Office of Pipeline Safety (see above).

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: April 30, 1998

In reply refer to: P-98-1 through -5

Ms. Kelley Coyner
Acting Administrator
Research and Special Programs Administration
400 7th Street, S.W.
Washington, D.C. 20590

Despite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel or other materials, the Safety Board notes that a number of pipeline accidents it has investigated have involved plastic piping that cracked in a brittle-like manner. For example, on October 17, 1994, an explosion and fire in Waterloo, Iowa, destroyed a building and damaged other property. Six persons died and seven were injured in the accident. The Safety Board investigation determined that natural gas had been released from a plastic service pipe that had failed in a brittle-like manner at a connection to a steel main.

The Safety Board also investigated a gas explosion that resulted in 33 deaths and 69 injuries in San Juan, Puerto Rico, in November 1996.[1] The Safety Board's investigation determined that the explosion resulted from ignition of propane gas that had migrated under pressure from a failed plastic pipe that displayed evidence of brittle-like circumferential cracking.

The Railroad Commission of Texas investigated a natural gas explosion and fire that resulted in one fatality in Lake Dallas, Texas. in August 1997.[2] A metal pipe pressing against a plastic pipe generated stress intensification that led to a brittle-like crack in the plastic pipe.

A broader Safety Board survey of the accident history of plastic piping suggested that the material may be susceptible to premature brittle-like cracking under conditions of stress intensification. No statistics exist that detail how much and from what years any plastic piping may already have been replaced; however, hundreds of thousands of miles of plastic piping have been installed, with a significant amount of it having been installed prior to the mid-1980s. Any

[1] For more information, see National Transportation Safety Board Pipeline Accident Report--*San Juan Gas Company, Inc./Enron Corp, Propane Gas Explosion in San Juan, Puerto Rico, on November 21, 1996* (NTSB/PAR-97/01).

[2] Railroad Commission of Texas Accident Investigation No 97-AI-055, October 31, 1997

vulnerability of this material to premature failure could represent a serious potential hazard to public safety.

In an attempt to gauge the extent of brittle-like failures in plastic piping and to assess trends and causes, the Safety Board examined pipeline accident data compiled by RSPA. The examination revealed that the data were insufficient to serve as a basis for assessing the long-term performance of plastic pipe.

Lacking adequate data from RSPA, the Safety Board reviewed published technical literature and contacted more than 20 experts in gas distribution plastic piping to determine the estimated frequency of brittle-like cracks in plastic piping. The majority of the published literature and experts indicated that failure statistics would be expected to vary from one gas system operator to another based on factors such as brands and dates of manufacture of plastic piping in service, installation practices, and ground temperatures, but they indicated that brittle-like failures, as a nationwide average, may represent the second most frequent failure mode for older plastic piping, exceeded only by excavation damage.

The Safety Board asked several gas system operators about their direct experience with brittle-like cracks. Four major gas system operators reported that they had compiled failure statistics sufficient to estimate the extent of brittle-like failures. Three of those four said that brittle-like failures are the second most frequent failure mode in their plastic pipeline systems. One of these operators supplied data showing that it experienced at least 77 brittle-like failures in plastic piping in 1996 alone.

As an outgrowth of the Safety Board's investigations into the Waterloo, Iowa; San Juan, Puerto Rico; and about a dozen other accidents, and in view of indications that some plastic piping, particularly older piping, may be subject to premature failure attributable to brittle-like cracking, the Safety Board undertook a special investigation of polyethylene gas service pipe. The investigation addressed the following safety issues:[3]

- The vulnerability of plastic piping to premature failures due to brittle-like cracking;
- The adequacy of available guidance relating to the installation and protection of plastic piping connections to steel mains; and
- Performance monitoring of plastic pipeline systems as a way of detecting unacceptable performance in piping systems.

The Waterloo, San Juan, and Lake Dallas accidents were only three of the most recent in a series of accidents in which brittle-like cracks in plastic piping have been implicated. In Texas in 1971, natural gas migrated into a house from a brittle-like crack at the connection of a plastic

[3]For more information, see National Transportation Safety Board Pipeline Special Investigation Report-- *Brittle-like Cracking in Plastic Pipe for Gas Service* (NTSB/SIR-98/01).

service line to a plastic main.[4] The gas ignited and exploded, destroying the house and burning one person. The investigation determined that vertical loading over the connection generated long-term stress that led to the crack.

A 1973 natural gas explosion and fire in Maryland severely damaged a house, killed three occupants, and injured a fourth.[5] The Safety Board's investigation revealed that a brittle-like crack occurred in a plastic pipe as a result of an occluded particle that created a stress point.

The Safety Board's investigation of a natural gas explosion and fire that resulted in three fatalities in North Carolina in 1975[6] determined that the gas had accumulated because a concrete drain pipe resting on a plastic service pipe had precipitated two cracks in the plastic pipe. Available documentation suggests that these cracks were brittle-like.

A 1978 natural gas accident in Arizona destroyed 1 house, extensively damaged 2 others, partially damaged 11 other homes, and resulted in 1 fatality and 5 injuries.[7] Available documentation indicates that the gas line crack that caused the accident was brittle-like.

A 1978 accident in Nebraska involved the same brand of plastic piping as that involved in the Waterloo accident. A crack in a plastic piping fitting resulted in an explosion that injured one person, destroyed one house, and damaged three other houses.[8] The Safety Board determined that inadequate support under the plastic fitting resulted in long-term stress intensification that led to the formation of a circumferential crack in the fitting. Available documentation indicates that the crack was brittle-like.

A December 1981 natural gas explosion and fire in Arizona destroyed an apartment, damaged five other apartments in the same building, damaged nearby buildings, and injured three occupants.[9] The Safety Board's investigation determined that assorted debris, rocks, and chunks of concrete in the excavation backfill generated stress intensification that resulted in a circumferential crack in a plastic pipe at a connection to a plastic fitting. Available documentation indicates that the crack was brittle-like.

A July 1982 natural gas explosion and fire in California destroyed a store and two residences, severely damaged nearby commercial and residential structures, and damaged

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[4]National Transportation Safety Board Pipeline Accident Report--*Lone Star Gas Company, Fort Worth, Texas, October 4, 1971* (NTSB/PAR-72/5).

[5]National Transportation Safety Board Pipeline Accident Report--*Washington Gas Light Company, Bowie, Maryland, June 23, 1973* (NTSB/PAR-74/5).

[6]National Transportation Safety Board Pipeline Accident Brief--"Natural Gas Corporation, Kinston, North Carolina, September 29, 1975."

[7]National Transportation Safety Board Pipeline Accident Brief--"Arizona Public Service Company, Phoenix, Arizona, June 30, 1978."

[8]National Transportation Safety Board Pipeline Accident Brief--"Northwestern Public Service, Grand Island, Nebraska, August 28, 1978."

[9]National Transportation Safety Board Pipeline Accident Brief--"Southwest Gas Corporation, Tucson, Arizona, December 3, 1981."

automobiles.[10] The Safety Board's investigation identified a longitudinal crack in a plastic pipe as the source of the gas leak that led to the explosion. Available documentation indicates that the crack was brittle-like.

A September 1983 natural gas explosion in Minnesota involved the same brand of plastic piping as that involved in the Waterloo and Nebraska accidents.[11] The explosion destroyed one house and damaged several others, and injured five persons. The Safety Board's investigation determined that rock impingement generated stress intensification that resulted in a crack in a plastic pipe. Available documentation indicates that the crack was brittle-like.

One woman was killed and her 9-month-old daughter injured in a December 1983 natural gas explosion and fire in Texas.[12] The Safety Board's investigation determined that the source of the gas leak was a brittle-like crack that had resulted from damage to the plastic pipe during an earlier squeezing operation to control gas flow.[13]

A September 1984 natural gas explosion in Arizona resulted in five fatalities, seven injuries, and two destroyed apartments.[14] The Safety Board's investigation determined that a reaction between a segment of plastic pipe and some liquid trapped in the pipe weakened the pipe and led to a brittle-like crack.

Excavations following the Waterloo, Iowa, accident uncovered, at a depth of about 3 feet, a 4-inch steel main.[15] Welded to the top of the main was a steel tapping tee. Connected to the steel tee was a 1/2-inch plastic service pipe. Markings on the plastic pipe indicated that it was a medium-density polyethylene material manufactured on June 11, 1970, in accordance with American Society for Testing and Materials (ASTM) standard D2513. The pipe had been marketed by Century Utility Products, Inc. (Century). The plastic pipe was found cracked at the end of the tee's internal stiffener and beyond the coupling nut.

The investigation determined that much of the top portion of the circumference of the pipe immediately outside the tee's internal stiffener displayed several brittle-like slow crack initiation and growth fracture sites. These slow crack fractures propagated on almost parallel planes slightly offset from each other through the wall of the pipe. As the slow cracks from different planes continued to grow and began to overlap one another, ductile tearing occurred

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[10]National Transportation Safety Board Pipeline Accident Brief--"Pacific Gas and Electric Company, San Andreas, California, July 8, 1982."

[11]National Transportation Safety Board Pipeline Accident Brief--"Northern States Power Company, Newport, Minnesota, September 19, 1983."

[12]National Transportation Safety Board Pipeline Accident Brief--"Lone Star Gas Company, Terell, Texas, December 9, 1983."

[13]Plastic pipe is sometimes squeezed to control the flow of gas. In some cases, squeezing plastic pipe can damage it and make it more susceptible to brittle-like cracking.

[14]National Transportation Safety Board Pipeline Accident Report--*Arizona Public Service Company Natural Gas Explosion and Fire, Phoenix, Arizona, September 25, 1984* (NTSB/PAR-85/01).

[15]For more information, see Pipeline Accident Brief in appendix to National Transportation Safety Board Pipeline Special Investigation Report--*Brittle-like Cracking in Plastic Pipe for Gas Service*.

between the planes. Substantial deformation was observed in part of the fracture; however, the initiating cracks were still classified as brittle-like.

Samples recovered from the plastic service line underwent several laboratory tests under the supervision of the Safety Board. Two of these tests were meant to roughly gauge the pipe's susceptibility to brittle-like cracking. These tests were a compressed ring environmental stress crack resistance (ESCR) test in accordance with ASTM F1248 and a notch tensile test known as a PENT test that is now ASTM F1473. Lower failure times in these tests indicate a greater susceptibility to brittle-like cracking under the test conditions. The ESCR testing of 10 samples from the pipe yielded a mean failure time of 1.5 hours, and the PENT testing of 2 samples yielded failure times of 0.6 and 0.7 hours. Test values this low have been associated with materials having poor performance histories[16] characterized by high leakage rates at points of stress intensification due to crack initiation and slow crack growth typical of brittle-like cracking. The Safety Board has investigated two other pipelines accidents, one in Nebraska in 1978 and one in Minnesota in 1983, that involved Century piping. The Safety Board is also aware of four other accidents that it did not investigate that involved the same brand of piping.

The Century pipe involved in the Waterloo accident was made from Union Carbide's DHDA 2077 Tan resin. Although Union Carbide's laboratory data supported Union Carbide's claimed strength, the Safety Board's review of the same data showed that the material had an early ductile-to-brittle transition, indicating poor resistance to brittle-like fractures.

In the early 1970s, a Minnesota gas system operator tested a number of piping products made from DHDA 2077 Tan resin, including those marketed by Century, as part of its comprehensive specification, testing, and evaluation program. The company rejected piping made from the Union Carbide product for use in its system based on the results of sustained pressure tests. Union Carbide, in 1971, acknowledged that its DHDA 2077 Tan resin material had a lower pressure rating at 100 °F than did DuPont's polyethylene pipe material.

Midwest Gas, the Waterloo, Iowa, gas operator at the time of the explosion and fire, had experienced at least three other significant failures involving Century pipe. The most recent failures, occurring between 1992 and 1994, prompted the company to collect samples of the Century material for independent laboratory testing. Samples were being gathered for testing at the time of the Waterloo accident. The subsequent laboratory report indicated that the Century piping had poor resistance to slow crack growth.

Midwest Gas's subsequent analysis of the company's leakage history concluded that its installations with Century piping had failure rates significantly higher than those with piping

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[16]Uralil, F. S., et al., *The Development of Improved Plastic Piping Materials and Systems for Fuel Gas Distribution—Effects of Loads on the Structural and Fracture Behavior of Polyolefin Gas Piping*, Gas Research Institute Topical Report, 1/75 - 6/80, NTIS No. PB82-180654, GRI Report No. 80/0045, 1981; Hulbert, L. E., Cassady, M. J., Leis, B. N., Skidmore, A., *Field Failure Reference Catalog for Polyethylene Gas Piping, Addendum No. 1*, Gas Research Institute Report No. 84/0235.2, 1989; and Brown, N. and Lu, X., "Controlling the Quality of PE Gas Piping Systems by Controlling the Quality of the Resin," *Proceedings, Thirteenth International Plastic Fuel Gas Pipe Symposium*, pp. 327-338, American Gas Association, Gas Research Institute, Battelle Columbus Laboratories, 1993.

from other manufacturers. Midwest Gas had received warnings from two pipe fitting manufacturers against use of their products with Century pipe because of Century pipe's susceptibility to brittle-like cracking. The current operating company in the Waterloo, Iowa, area, MidAmerican Energy, has, since the accident, replaced all the identified Century piping in its gas pipeline system.

The Safety Board concluded that plastic pipe extruded by Century Utility Products, Inc., and made from Union Carbide's DHDA 2077 Tan resin has poor resistance to brittle-like cracking under stress intensification, and this characteristic contributed to the Waterloo, Iowa, accident.

While Century piping has been identified specifically as being subject to brittle-like cracking (slow crack growth), evidence suggests that much of the early polyethylene piping may be more susceptible to such cracking than originally thought and thus may also be subject to premature failure.

The procedure used in the United States to rate the strength of plastic pipe, which was developed in the early 1960s, involved subjecting test piping to different stress values and recording how much time elapsed before the piping ruptured. The stress rupture data of the samples were then plotted, and a best-fit straight line was derived to represent the material's decline in rupture resistance as its time under stress increased.

To meet the requirements of the procedure, at least one tested sample had to be able to withstand stress rupture testing until at least 10,000 hours, or slightly more than 1 year. The straight line that was plotted to describe the data for this material was extrapolated out by a factor of 10, to 100,000 hours (about 11 years). The point at which the sloping straight line intersected the 100,000-hour point indicated the appropriate hydrostatic design basis for this material.

A key assumption characterized the assignment of a hydrostatic design basis under the procedure: The procedure assumed that the gradual decline in the strength of plastic piping material as it was subjected to stress over time would continue to be described by a straight line. In the early 1960s, the industry had little long-term experience with plastic piping, and a straight line seemed to represent the response of the material to laboratory stress testing. With little other information on which to base strength estimations, the straight-line assumption appeared valid. This procedure and assumption for rating the strength were incorporated into industry and government requirements.

As experience grew with plastic piping materials and as better testing methods were developed, however, the straight-line assumptions of the procedure came to be challenged. Elevated-temperature testing indicated that polyethylene piping can exhibit a decline in strength that does not follow the straight-line assumption, but instead shows a downturn. The difference between the actual (falloff) and projected (straight line) strengths became even more pronounced as the lines were extrapolated beyond 100,000 hours.

The combination of more durable modern plastic piping materials and more realistic strength testing has rendered the strength ratings of modern plastic piping much more reliable.

Unfortunately, much of the early plastic piping was sold and installed with expectations of strength and long-term performance that, because they were based on questionable assumptions about long-term performance, may not have been valid. This is borne out by data from a variety of sources. The history of strength rating requirements, a review of the piping properties and literature, and observations of several experts with extensive experience in plastic piping, all suggest that much of the polyethylene pipe, depending upon the brands, manufactured from the 1960s through the early 1980s fails at lower stresses and after less time than originally projected. The Safety Board therefore concluded that the procedure used in the United States to rate the strength of plastic pipe may have overrated the strength and resistance to brittle-like cracking of much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s.

Another important assumption of the design protocol for plastic pipe involved the ductility of the materials. It was assumed, based on short-term tests, that plastic piping had long-term ductile properties. Ductile material, by bending, expanding, or flexing, can redistribute stress concentrations better than can brittle material, such as cast iron. Notable from results of tests performed under the strength-rating procedure was that those short-term stress ruptures in the testing process tended to be characterized by substantial material deformation in the area of the rupture. This deformation described a material with obvious ductile properties. However, it was shown that, as time-to-failure increased in stress rupture tests, failures in several materials occurred as slit failures that, because they were not accompanied by substantial deformation, were more typical of brittle-like failures. These slit or brittle-like failures were characterized by crack initiation and slow crack growth. The procedure used to rate the strength of plastic pipe did not distinguish between ductile fractures and slit fractures and assumed that both types of failures would be described by the same straight line.

The assumption of ductility of plastic piping had important safety ramifications. For example, a number of experts believed it was safe to design plastic piping installations based on stresses primarily generated by internal pressure and to give less consideration to stress intensification generated by external loading. Ductile material reduces stress intensification by localized yielding, or deformation.

As noted previously, laboratory data supported the strength rating assigned to DHDA 2077 Tan resin by the process used at the time to rate strength; nevertheless, the material showed evidence of early ductile-to-brittle transition. The fact that the process used to measure the long-term durability of piping materials did not reveal the susceptibility to premature brittle-like cracking of the DHDA 2077 Tan material highlights the weaknesses of the process in use at the time. More significantly, it calls into question the durability of other early materials that were rated using the same process and that remain in service today. This concern is heightened by the fact that, in addition to the Waterloo accident involving Century pipe and DHDA 2077 Tan resin, other accidents investigated or documented by the Safety Board have demonstrated that brittle-like cracking occurs in other older plastic piping as well.

All available evidence indicates that polyethylene piping's resistance to brittle-like cracking has improved significantly through the years. Several experts in gas distribution plastic piping have told the Safety Board that a majority of the polyethylene piping manufactured in the 1960s and early 1970s had poor resistance to brittle-like cracking, while only a minority of that manufactured by the early 1980s could be so characterized.[17] Several gas system operators have told the Safety Board that they are aware of no instances of brittle-like cracking with their own modern polyethylene piping installations.

Premature brittle cracking in plastic piping is a complex phenomenon. Without clear and straightforward communication to pipeline operators about brands of piping and conditions that increase the likelihood of brittle cracking, many pipeline operators may not have the knowledge to make good decisions affecting public safety. Some of these key decisions include how often to conduct leak surveys and whether to repair or replace portions of pipeline systems.

Frequently, piping manufacturers, because they can receive feedback from a number of customers, are the first to learn of systemic problems with their products. For small operators, contact with a manufacturer may be the major source of outside communication about poorly performing products. Unfortunately, while manufacturers have a high degree of technical expertise regarding their products, they may also tend to aggressively publicize the best performance characteristics of their products while only reluctantly acknowledging weaknesses. The Safety Board is aware of only a very few cases in which manufacturers of resin or pipe have formally notified the gas industry of materials having poor resistance to brittle cracking.

Thus, although reputable manufacturers commonly provide essential technical assistance and serve as partners to pipeline operators, operators are still responsible for evaluating and determining which products are most likely to maintain the integrity of their pipeline systems. Furthermore, perhaps because the possibility of premature failure of plastic piping due to brittle-like cracking has not been fully appreciated within the industry and the scope of the potential problem has not been fully measured, the Federal Government has not provided information on this issue to gas system operators. The Safety Board concluded that gas pipeline operators have had insufficient notification that much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s may be susceptible to brittle-like cracking and therefore may not have implemented adequate pipeline surveillance and replacement programs for their older piping.

In the view of the Safety Board, manufacturers of resin and pipe should do more to notify pipeline operators about the poor brittle-crack resistance of some of their past products. The Plastics Pipe Institute (PPI) is the manufacturers' organization that covers most of the major resin and pipe producers, many of whom have manufactured resin and pipe for several years. The Safety Board therefore recommended that the PPI advise its members to notify pipeline system operators if any of their piping products, or materials used in the manufacture of piping products, currently in service for natural gas or other hazardous materials indicate poor resistance to brittle-like failure.

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[17] A number of these experts considered material to have poor resistance to brittle-like cracking if the material was shown to have brittle-like fractures in stress rupture testing at 73 °F before 100,000 hours.

Based on evidence examined by the Safety Board, the premature transition of plastic piping from ductile failures to brittle failures appears to have little observable adverse impact on the serviceability of plastic piping except in those instances in which undamaged piping is subjected to stress intensification generated by external forces. Unfortunately, stress intensification, which can take many forms, has been found in a number of gas piping systems. Rock impingement, soil settlement, and excess pipe bending are among the potential sources of stress intensification, and the combination of piping with poor resistance to brittle-like cracking and external forces can lead to significant rates of failures. These failures can, in turn, lead to serious accidents. The Safety Board therefore concluded that much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s may be susceptible to premature brittle-like failures when subjected to stress intensification, and these failures represent a potential public safety hazard.

Examples of conditions that can generate stress intensification include differential earth settlement, particularly at connections with more rigidly anchored fittings; excessive bending as a result of installation configurations, especially at fittings; and point contact with rocks or other objects. The Safety Board special investigation determined that much of the available guidance to gas system operators for limiting stress intensification at plastic pipeline connections to steel mains is inadequate or ambiguous. Based on its review of this guidance and on the history of the plastic pipeline accidents it has investigated, the Safety Board concluded that, because guidance covering the installation of plastic piping is inadequate for limiting stress intensification at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces.

Subsequent to the Waterloo accident, personnel from the Iowa Department of Commerce, after discussions with OPS personnel, stated that the Waterloo installation was not in violation of 49 CFR 192.361, which specifies minimum pipeline safety standards for the installation of gas service piping. They further stated that, while they agree that the installation of protective sleeves at pipeline connections is prudent, a specific requirement to install protective sleeves is beyond the scope of Part 192 and is inconsistent with the regulation's performance orientation.

The Transportation Safety Institute (TSI) conducts training classes for Federal and State pipeline inspectors. TSI instructors advise class participants that many of the performance-oriented regulations within Part 192 can only be found to be violated if the gas system fails in a way that demonstrates that the regulation was not followed. The TSI acknowledges the difficulty of identifying violations under paragraph 192.361(d). A TSI instructor told the Safety Board that, in the case of the failed pipe at Waterloo, the installation could not be faulted under Part 192 because of the length of time (23 years) between the installation date and the failure date.

RSPA acknowledges that the regulation that requires gas service lines to be installed so as to minimize anticipated piping strain and external loading lacks performance measurement criteria. The Safety Board pointed out in a previous accident investigation report[18] that, although

[18]National Transportation Safety Board Pipeline Accident Report, *Kansas Power and Light Company Natural Gas Pipeline Accidents, September 16. 1988 to March 29. 1989* (NTSB/PAR-90/03).

the OPS considers many of its pipeline safety regulations to be performance-oriented requirements, many are no more than general statements of required actions that do not establish any criteria against which the adequacy of the actions taken can be evaluated. The Safety Board has further stated that regulations that do not contain measurable standards for performance make it difficult to determine compliance with the requirement. The Safety Board therefore previously recommended that RSPA:

> Evaluate each of its pipeline safety regulations to identify those that do not contain explicit objectives and criteria against which accomplishment of the objective can be measured; to the extent practical, revise those that are so identified. (P-90-15)

As a result of this safety recommendation, the OPS asked the National Association of Pipeline Safety Representatives liaison committee to review the 20 regulations deemed to be the least enforceable due to lack of clarity. The Safety Board has encouraged RSPA to make such a review a periodic effort so that all of the regulations, not just the specified 20, are continually clarified. The last correspondence to the Safety Board from the OPS regarding this recommendation was on March 8, 1993, and the recommendation has remained classified "Open—Acceptable Response." In an October 31, 1997, letter to the OPS, the Safety Board inquired as to the status of 28 open safety recommendations to RSPA, including P-90-15. The OPS has not yet provided a written response for P-90-15. The Safety Board will continue to follow the progress and urge completion of this recommendation.

Federal regulations require that gas pipeline system operators have in place an ongoing program to monitor the performance of their piping systems. Before the Waterloo accident, Midwest Gas developed only a limited capability for monitoring and analyzing the condition of its gas system. For example, the company did not statistically correlate failure rates to the amounts of installed pipe or components provided by specific manufacturers. The design of the program meant that the relatively few areas with high failure rates (for example, those with Century pipe) were aggregated with and therefore masked by the large number of plastic piping installations that had low failure rates. Thus, the Midwest Gas surveillance program did not reveal the high failure rates associated with Century pipe. Only after the accident did Midwest Gas identify the Century pipe within its pipeline system as having high failure rates, even though the company could have collected and processed the same type of data and reached the same determination before the accident. If Midwest Gas had further correlated its data to years of installation, it may have also been able to examine the effects of its changing installation methods or changes in performance with different manufacturers through the years.

The Safety Board concluded that, before the Waterloo accident, the systems used by Midwest Gas Company for tracking, identifying, and statistically characterizing plastic piping failures did not permit an effective analysis of system failures and leakage history. The Safety Board further concluded that if, before the Waterloo accident, Midwest Gas had had an effective surveillance program that tracked and identified the high leakage rates associated with Century piping when subjected to stress intensification, the company could have implemented a replacement program for the pipe and may have replaced the failed service connection before the accident.

Since the accident, MidAmerican Energy has revised its systems, adding parameters to provide the company with added capability to sort failures. However, MidAmerican Energy has not chosen parameters that will allow an adequate analysis of its plastic piping system failures and leakage history. For example, the generic "improper installation" is a parameter to be linked to leaks; however, no parameters have been added for the presence, lack, improper design, or improper placement of a protective sleeve. And no parameters have been added to link leaks to squeeze locations, improper joining, or items to differentiate between insufficient support and excessive installed bending. The Safety Board therefore concluded that MidAmerican Energy's current systems for tracking, identifying, and statistically characterizing plastic piping failures do not enable an effective analysis of system failures and leakage history.

In a previous accident investigation report,[19] the Safety Board pointed out that many operators had not established procedures to comply with Federal regulations requiring surveillance and investigation of failures. The Safety Board recommended that RSPA:

> Emphasize, as a part of OPS inspections and during training and state monitoring programs, the actions expected of gas operators to comply with the continuing surveillance and failure investigation, including laboratory examination requirements. (P-90-14)

In a letter to the Safety Board, RSPA responded that the TSI had increased emphasis on gas surveillance and failure investigation in the operations block of its industry seminars held across the country. The letter stated that the TSI would incorporate a discussion of accident analysis into a new hazardous liquids seminar that was to be presented for the first time in FY 1992. Additionally, RSPA noted that it planned to place additional emphasis on continuing surveillance and failure investigation requirements in its new inspection forms at the time of the next revision. Based on this response, the Safety Board classified Safety Recommendation P-90-14 "Closed—Acceptable Action."

Despite the RSPA response to this safety recommendation, for a variety of reasons—including the inadequate performance monitoring programs found at Midwest Gas/MidAmerican Energy, the susceptibility to brittle cracking of much of the polyethylene piping installed through the early 1980s, deficiencies noted in gas industry communications regarding poorly performing brands of polyethylene piping, and differences noted in the performance of different types and brands of polyethylene piping—RSPA may need to do more. Gas system operators may need to be advised once again of the importance of complying with Federal requirements for piping system surveillance and analyses. As is the case with older piping, an effective plastic pipeline surveillance program would be based on factors such as piping manufacturer, installation date, pipe diameter, operating pressure, leak history, geographical location, modes of failure (such as bending,

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[19]National Transportation Safety Board Pipeline Accident Report--*Kansas Power and Light Company Natural Gas Pipeline Accidents, September 16, 1988, to March 29, 1989*.

inadequate support, rock impingement, or improper joining), location of failure (such as at the main to service or at pipe squeeze locations), and other factors such as the presence, absence, or misapplication of a sleeve. An effective program would also evaluate past piping and components installed, as well as past installation practices, to provide a basis for the replacement, in a planned, timely manner, of plastic piping systems that indicate unacceptable performance.

The expressed purpose of RSPA's *Guidance Manual for Operators of Small Natural Gas Systems* is to assist nontechnically trained persons who operate small gas systems. However, the manual provides no caution against bending close to a plastic service connection to a steel main. The manual recommends following manufacturers' instructions and indicates that a properly designed sleeve should be used at this connection, which would address designing the sleeve with the proper diameter and length. However, none of the steel tapping tee manufacturers has recommended precautions to limit stresses at the service to main connection; therefore, nontechnically trained persons may not realize the importance of determining these parameters.

The National Transportation Safety Board therefore makes the following safety recommendations to the Research and Special Programs Administration:

> Notify pipeline system operators who have installed polyethylene gas piping extruded by Century Utility Products, Inc., from Union Carbide Corporation DHDA 2077 Tan resin of the piping's poor brittle-crack resistance. Require these operators to develop a plan to closely monitor the performance of this piping and to identify and replace, in a timely manner, any of the piping that indicates poor performance based on such evaluation factors as installation, operating, and environmental conditions; piping failure characteristics; and leak history. (P-98-1)

> Determine the extent of the susceptibility to premature brittle-like cracking of older plastic piping (beyond that piping marketed by Century Utility Products, Inc.) that remains in use for gas service nationwide. Inform gas system operators of the findings and require them to closely monitor the performance of the older plastic piping and to identify and replace, in a timely manner, any of the piping that indicates poor performance based on such evaluation factors as installation, operating, and environmental conditions; piping failure characteristics; and leak history. (P-98-2)

> Immediately notify those States and territories with gas pipeline safety programs of the susceptibility to premature brittle-like cracking of much of the plastic piping manufactured from the 1960s through the early 1980s and of the actions that the Research and Special Programs Administration will require of gas system operators to monitor and replace piping that indicates unacceptable performance. (P-98-3)

> In cooperation with the manufacturers of products used in the transportation of gases or liquids regulated by the Office of Pipeline Safety, develop a mechanism by which the Office of Pipeline Safety will receive copies of all safety-related notices, bulletins, and other communications regarding any defect, unintended

deviation from design specification, or failure to meet expected performance of any piping or piping product that is now in use or that may be expected to be in use for the transport of hazardous materials. (P-98-4)

Revise the *Guidance Manual for Operators of Small Natural Gas Systems* to include more complete guidance for the proper installation of plastic service pipe connections to steel mains. The guidance should address pipe bending limits and should emphasize that a protective sleeve, in order to be effective, must be of the proper length and inner diameter for the particular connection and must be positioned properly. (P-98-5)

Also, the National Transportation Safety Board issued Safety Recommendations P-98-6 to the Gas Research Institute; P-98-7 through -9 to the Plastics Pipe Institute; P-98-10 to the Gas Piping Technology Committee; P-98-11 and -12 to the American Society for Testing and Materials; P-98-13 to the American Gas Association; P-98-14 and -15 to MidAmerican Energy Corporation; P-98-16 and -17 to Continental Industries, Inc.; P-98-18 to Dresser Industries, Inc.; P-98-19 to Inner-Tite Corporation; and P-98-20 to Mueller Company.

Please refer to Safety Recommendations P-98-1 through -5 in your reply. If you need additional information, you may call (202) 314-6469

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

Proposed Protocol for Managing Select Aldyl A Pipe in Avista Utilities' Natural Gas System

Attachment 4

Sept. 1, 1999 Dept of Transportation Potential Failure Due to Brittle-Like Cracking Certain Polyethylene Plastic Pipe Manufactured by Century Utility Products, Inc.

ADB-99-01

Sep 1, 1999

Billing Code: 4910-60-P
DEPARTMENT OF TRANSPORTATION
Pipeline and Hazardous Materials Safety Administration

Potential Failure Due to Brittle-Like Cracking Certain Polyethylene Plastic Pipe Manufactured by Century Utility Products Inc.

AGENCY: Pipeline and Hazardous Materials Safety Administration (PHMSA), DOT.

ACTION: Notice; issuance of advisory bulletin on Century polyethylene gas pipe to owners and operators of natural gas distribution systems.

SUMMARY: This advisory bulletin is directed at owners and operators of natural gas distribution systems that have installed plastic pipe extruded by Century Utility Products Inc. from Union Carbide Corporation's DHDA 2077 Tan medium density polyethylene resin (Century pipe). Pipe manufactured between 1970 and 1973 may fail in service due to its poor resistance to brittle-like cracking. Operators with Century pipe in their systems should closely monitor this pipe for leaks with increased leak survey frequency. Century pipe that may be improperly installed, repaired, or operating in an environment that impairs pipe strength should be replaced.

ADDRESS: This document can be viewed on the Office of Pipeline Safety (OPS) home page at: http://ops.dot.gov.

FOR FURTHER INFORMATION CONTACT: Gopala (Krishna) Vinjamuri at (202) 366- 4503, or by E-mail at vinjamuri@PHMSA.dot.gov.

SUPPLEMENTARY INFORMATION:

I. Background

The National Transportation Safety Board (NTSB) recently published the results of a special investigation into accidents that involved plastic pipe currently in use to deliver natural gas to residential and business use. The report, Brittle-Like Cracking in Plastic Pipe for Gas Service (NTSB/SIR-98/01; April 23, 1998) suggested that "[d]espite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel and other materials, [a] number of pipeline accidents investigated have involved plastic piping that cracked in a brittle-like manner." Copies of this report may be obtained from NTSB Public Inquiry Office by calling 202-314-6551.

The phenomenon of brittle-like cracking in plastic pipe as described in the NTSB report and generally understood within the plastic pipeline industry relates to a part-through crack initiation in the pipe wall followed by stable crack growth at stress levels much lower than the stress required for yielding, resulting in a very tight slit-like opening and gas leak. This failure mode is difficult to detect until significant amount of gas leaks out of the pipe, and potentially migrates into closed space such as basements of dwellings. Premature brittle-like cracking requires relatively high localized stress intensification that may be a result from geometrical discontinuities, excessive bending, improper fitting assemblies, and/or dents and gouges. Because this failure mode exhibits no evidence of gross yielding at the failure location, the term brittle-like cracking is used. This phenomenon is different from brittle fracture, in which the failure results in fragmentation of the pipe.

NTSB also alleged that the guidance provided by manufacturers and industry standards for the installation of plastic pipe is inadequate for limiting stress intensification, particularly at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces that may result in brittle-like cracking.

Century pipe

Between 1970 and 1973, Century Utility Products Inc. (a/k/a AMDEVCO), now defunct, marketed medium density polyethylene plastic pipe and fittings (Century pipe) in sizes ranging from ½ inch to 4 inches for use in natural gas distribution. These plastic pipes and fittings were manufactured by extrusion from Union Carbide Corporation's DHDA 2077 Tan resin, and was marked PE 2306 in accordance with American Society for Testing and Materials (ASTM) standards. Following investigation of a series of incidents, including the December 2, 1979, explosion in a residence in Tuscola, Illinois, and the October 17, 1994, accident in Waterloo, Iowa, that resulted in several fatalities, it was established that the

Union Carbide's DHDA 2077 Tan resin lacks adequate resistance to brittle-like cracking and is prone to relatively short life when subjected to high local stress concentration. The pipe in the Tuscola, Illinois, accident failed in less than 8 years, and the pipe in the Waterloo, Iowa, accident failed within 23 years in service. It has been established that Century pipe exhibited significantly higher leak rate in comparison with other polyethylene, steel, and cast iron pipe used in natural gas distribution systems.

Following the Waterloo, Iowa, accident, PHMSA has taken number of actions, including gathering Century pipe installation data. Also, remedial action has been taken by various operators in mid-western states where much of the Century pipe produced was known to have been installed. It is PHMSA's understanding that the operators having Century pipe in their systems have initiated close monitoring and some have replacement program in progress.

NTSB recommended that PHMSA notify owners and operators of natural gas systems who continue to use Century pipe of the potential for premature failures by brittle-like cracking and the need to "[d]evelop a plan to closely monitor the performance of and to identify and replace, in a timely manner, any piping that indicates poor performance based on such evaluation factors as installation, operating and environmental conditions, piping failure characteristics and leak history."

II. Advisory Bulletin (ADB-99-01)

To: Owners and Operators of Natural Gas Distribution Pipeline Systems

Subject: Susceptibility of certain polyethylene pipe manufactured by Century Utility Products Inc. to premature failure due to brittle-like cracking.

Purpose: To advise natural gas distribution pipeline owners and operators of the need to closely monitor and replace as necessary polyethylene natural gas pipe manufactured by Century Utility Products Inc. between 1970 and 1973 that is susceptible to brittle-like cracking.

Advisory: All owners and operators of natural gas distribution systems who have installed and continue to use polyethylene pipe extruded by Century Utility Products Inc, (now defunct) from the resin DHDA 2077 Tan resin manufactured by Union Carbide Corporation during the period 1970 to 1973 (Century pipe) are advised that this pipe may be susceptible to premature failure due to brittle-like cracking. Premature failures by brittle-like cracking of Century pipe is known to occur due to poor resin characteristics, excessive local stress intensification caused by improper joints, improper installation, and environments detrimental to pipe long-term strength. All distribution systems containing Century pipe should be monitored to identify pipe subject to brittle-like cracking. Remedial action, including replacement, should be taken to protect system integrity and public safety.

In addition, in light of the potential susceptibility of Century pipe to brittle-like cracking, PHMSA recommends that each natural gas distribution system operator with Century pipe revise their plastic pipe repair procedure(s) to exclude pipe pinching for isolating sections of Century pipe. Additionally, PHMSA recommends replacement of any Century pipe segment that has a significant leak history or which for any reason is of suspect integrity.

(49 U.S.C. Chapter 601; 49 CFR 1.53)

Issued in Washington, D.C. on ____________________.

Richard B. Felder

Associate Administrator for Pipeline Safety

Proposed Protocol for Managing Select Aldyl A Pipe in Avista Utilities' Natural Gas System

Attachment 5

Advisory Bulletin (ADB-02-7) Notification of the Susceptibility to Premature Brittle-like Cracking of Older Plastic Pipe

Advisory Bulletin (ADB-02-7)

[Notices][Page 70806-70808]
Billing Code: 4910-60-P

DEPARTMENT OF TRANSPORTATION

Research and Special Programs Administration

Notification of the Susceptibility to Premature Brittle-like Cracking of Older Plastic Pipe.

AGENCY: Research and Special Programs Administration (RSPA), DOT.

ACTION: Notice; issuance of advisory bulletin.

SUMMARY. RSPA is issuing this follow-up advisory bulletin to owners and operators of natural gas distribution systems to inform them of the susceptibility to premature brittle-like cracking of older plastic pipe and the voluntary efforts to collect and analyze data on plastic pipe performance. A Special Investigation Report issued by the National Transportation Safety Board (NTSB) described how plastic pipe installed in natural gas distribution systems from the 1960s through the early 1980s may be vulnerable to brittle-like cracking resulting in gas leakage and potential hazards to the public and property. On March 11, 1999, RSPA issued two advisory bulletins on this issue. The first bulletin reminded natural gas distribution system operators of the potential poor resistance to brittle-like cracking of certain polyethylene pipe manufactured by Century Utility Products, Inc. The second bulletin advised natural gas distribution system operators of the potential vulnerability of older plastic pipe to brittle-like cracking.

ADDRESS: This document can be viewed on the Office of Pipeline Safety (OPS) home page at: http://ops.dot.gov.

FOR FURTHER INFORMATION CONTACT: Gopala K. Vinjamuri, (202) 366-4503, or by email at gopala.vinjamuri@rspa.dot.gov.

SUPPLEMENTARY INFORMATION

I. Background

On April 23, 1998, NTSB issued a Special Investigation Report (NTSB/SIR-98/01), Brittle-like Cracking in Plastic Pipe for Gas Service, that describes how plastic pipe installed in natural gas distribution systems from the 1960s through the early 1980s may be vulnerable to brittle-like cracking resulting in gas leakage and potential hazards to the public and property. An NTSB survey of the accident history of plastic pipe suggested that the material may be susceptible to premature brittle-like cracking under conditions of local stress intensification because of improper joining or installation procedures. Hundreds of thousands of miles of plastic pipe have been installed, with a significant amount installed prior to the early-1980s. NTSB believes any vulnerability of this material to premature cracking could represent a potentially serious hazard to public safety. Copies of this report may be obtained by calling NTSB's Public Inquiry Office at 202-314-6551.

RSPA has already issued two advisory bulletins on this issue. The first advisory bulletin, ADB-99-O1, which was published in the Federal Register on March 11, 1999 (47 FR 12211), reminded natural gas distribution system operators of the potential poor resistance to brittle-like cracking of certain polyethylene pipe manufactured by Century Utility Products, Inc. The second advisory bulletin, ADB99-02, also published in the Federal Register on March 11, 1999 (47 FR 12212), advised natural gas distribution system operators of the potential brittle-like cracking vulnerability of plastic pipe installed between the 1960s and early 1980s.

The phenomenon of brittle-like cracking in plastic pipe as described in the NTSB report and generally understood within the plastic pipeline industry relates to a part-through crack initiation in the pipe wall followed by stable crack growth at stress levels much lower than the stress required for yielding, resulting in a very tight slit-like openings and gas leaks. Although significant cracking may occur at points of stress concentration and near improperly designed or installed fittings, small brittle-like cracks may be difficult to detect until a significant amount of gas leaks out of the pipe, and potentially migrates into an enclosed space such as a basement. Premature brittle-like cracking requires relatively high localized stress intensification that may be a result from geometrical discontinuities, excessive bending, improper installation of fittings, and dents and gouges. Because this failure mode exhibits no evidence of gross yielding at the failure location, the term brittle-like cracking is used. This phenomenon is different from brittle fracture, in which the pipe failure causes in fragmentation of the pipe.

The NTSB report suggests that the combination of more durable plastic pipe materials and more realistic strength testing has improved the reliability of estimates of the long-term hydrostatic strength of modern plastic pipe and fittings. The report also documents that older polyethylene pipe, manufactured from the 1960s through the early 1980s, may fail at lower stresses and after less time than was originally projected. NTSB alleges that past standards used to rate the long-term strength of plastic pipe may have overrated the strength and resistance to brittle-like cracking of much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s.

In 1998, NTSB made several recommendations to trade organizations and to RSPA on the need for a better understanding of the susceptibility of plastic pipe to brittle-like cracking. This advisory bulletin responds to one of the NTSB recommendations. It is that RSPA "[d]etermine the extent of the susceptibility to premature brittle-like cracking of older plastic piping (beyond that marketed by Century Utilities Products Inc.) that remains in use for gas service nationwide. Inform gas system operators of the findings and require them to closely monitor the performance of the older plastic piping and to identify and replace, in a timely manner, any of the piping that indicates poor performance based on such evaluation factors as installation, operating, and environmental conditions; piping failure characteristics; and leak history."

In order to obtain the most complete information on the extent of the susceptibility to premature brittlelike cracking of older plastic pipe, a meeting was convened in May 1999 with all the stakeholders to determine how information on older plastic pipe could be assembled. The meeting included representatives of the American Gas Association (AGA), the American Public Gas Association (APGA), the Gas Research Institute (GRI) (now the Gas Technology Institute), the Midwest Energy Association (MEA), and the Plastic Pipe Institute (PPI).

As a result of the May 1999 meeting, the Joint Government-Industry Plastic Pipe Study Committee was formed to address the recommendations of the NTSB Special Investigation Report. The committee held three separate meetings to prepare a draft response to the NTSB recommendations and a draft industry notification of brittle-like cracking problems, the subject of this advisory bulletin. The committee membership consisted of a representative from OPS, a gas distribution operator from AGA, and the Transportation Safety Institute. Meetings were facilitated by General Physics Corporation, Columbia, MD. One of the committee findings was that there is a lack of data available from the industry to completely identify older plastic pipe that is still in service and may be susceptible to brittle-like cracking.

This finding led to the formation of the Plastic Pipe Database Committee (PPDC) to develop a process for gathering data on future plastic pipe failures with involvement from the states, which have assumed the authority from OPS over gas distribution systems, where most of the plastic pipe is installed. The PPDC is comprised of representatives from Federal and State regulatory agencies and from the natural gas and plastic pipe industries. Members include AGA, APGA, PPI, the National Association of Regulatory Utility Commissioners (NARUC), the National Association of Pipeline Safety Representatives (NAPSR), and OPS.

The PPDC database is expected to improve the knowledge base of gas utility operators and regulators and is intended to help reveal any failure trends associated with older plastic piping materials. The PPDC's mission is "to develop and maintain a voluntary data collection process that supports the analysis of the frequency and causes of in-service plastic piping material failures." It provides an opportunity for government and industry to work together to evaluate the extent of plastic pipe performance problems and to mitigate any risks to safety. The PPDC started gathering data in January 2001 from OPS and State pipeline safety agencies. For more information on the PPDC, go to the AGA web page (www.aga.org), and enter "PPDC" in the keyword search.

II. Advisory Bulletin (ADB-02-7)

To: Owners and Operators of Natural Gas Distribution Pipeline Systems

Subject: Notification of the Susceptibility to Premature Brittle-like Cracking of Older Plastic Pipe.

Advisory: In recent years, brittle-like cracking has been observed in some polyethylene pipes installed in gas service through the early 1980s. This brittle-like cracking (also known as slow crack growth) can substantially reduce the service life of polyethylene piping systems.

The susceptibility of some polyethylene pipes to brittle-like cracking is dependent on the resin, pipe processing, and service conditions. A number of studies have been conducted on older polyethylene

pipe. These studies have shown that some of these older polyethylene pipes are more susceptible to brittle-like cracking than current materials. These older polyethylene pipe materials include the following:

· Century Utility Products, Inc. products.

· Low-ductile inner wall "Aldyl A" piping manufactured by Dupont Company before 1973.

· Polyethylene gas pipe designated PE 3306. (As a result of poor performance this designation was removed from ASTM D-2513.)

The environmental, installation, and service conditions under which the piping is used are factors that could lead to premature brittle-like cracking of these older materials. These conditions include, but are not limited to:

· Inadequate support and backfill during installation

· Rock impingement

· Shear/bending stresses due to differential settlement resulting from factors such as:

o Excavation in close proximity to polyethylene piping o Directional drilling in close proximity to polyethylene piping

o Frost heave

· Bending stresses due to pipe installations with bends exceeding recommended practices

· Damaging squeeze-off practices

Service temperatures and service pressures also influence the service life of polyethylene piping. Piping installed in areas with higher ground temperatures or operated under higher operating pressures will have a shorter life.

Gas system operators may experience an increase in failure rates with a susceptible material. A susceptible material may have leak-free performance for a number of years before brittle-like cracks occur. An increase in the occurrence of leaks will typically be the first indication of a brittle-like cracking problem. It is the responsibility of each pipeline operator to monitor the performance of their gas system. RSPA issues the following recommendations to aid operators in identifying and managing brittle-like cracking problems in polyethylene piping involving taking appropriate action, including replacement, to mitigate any risks to public safety.

Because systems without known susceptible materials may also experience brittle-like cracking problems, RSPA recommends that all operators implement the following practices for all polyethylene piping systems:

1. Review system records to determine if any known susceptible materials have been installed in the system. Both engineering and purchasing records should be reviewed. Based on the available records, identify the location of the susceptible materials. More frequent inspection and leak surveys should be performed on systems that have exhibited brittle-like cracking failures of known susceptible materials.

2. Establish a process to identify brittle-like cracking failures. Identification of failure types and site installation conditions can yield valuable information that can be used in predicting the performance of the system.

3. Use a consistent record format to collect data on system failures. The AGA Plastic Failure Report form (Appendix F of the AGA Plastic Pipe Manual) provides an example of a report for the collection of failure data.

4. Collect failure samples of polyethylene piping exhibiting brittle-like cracking. Evidence of brittle-like cracking may warrant laboratory testing. Although every failure may not warrant testing, collecting samples at the time of

failure would provide the opportunity to conduct future testing should it be deemed necessary.

5. Whenever possible record the print line from any piping that has been involved in a failure. The print line information can be used to identify the resin, manufacturer and year of manufacture for plastic piping.

6. For systems where there is no record of the piping material, consider recording print line data when piping is excavated for other reasons. Recording the print line data can aid in establishing the type and extent of polyethylene piping used in the system.

(49 U.S.C. chapter 601; 49 CFR 1.53)
Issued in Washington, DC, on November 21, 2002.

Stacey L. Gerard
Associate Administrator for Pipeline Safety.

[FR Doc. 02-30055 Filed 11-25-02; 8:45 am]

Advisory Bulletin (ADB-02-7) - Correction

[Notices][Page 72027]

DEPARTMENT OF TRANSPORTATION

Research and Special Programs Administration

Notification of the Susceptibility to Premature Brittle-Like Cracking of Older Plastic Pipe

AGENCY: Research and Special Programs Administration (RSPA), DOT.

ACTION: Notice; correction.

SUMMARY: In the Federal Register of November 26, 2002, (67 FR 70806) the Research and Special Programs Administration (RSPA) published a notice document issuing an advisory bulletin on the susceptibility to premature brittle-like cracking of older plastic pipe (ADB-02-7). RSPA is submitting this correction notice to reflect minor wording changes and include a website address.

EFFECTIVE DATE: This correction takes effect November 26, 2002.

FOR FURTHER INFORMATION CONTACT: Gopala K. Vinjamuri, (202) 366-4503, or by email at gopala.vinjamuri@rspa.dot.gov.

SUPPLEMENTARY INFORMATION:

Correction

The last sentence in the first paragraph of the Supplementary Information heading under I. Background, reads:

Copies of this report may be obtained by calling NTSB's Public Inquiry Office at 202-314-6551.

We are revising this sentence to add NTSB's website address. The sentence is revised to read as follows:

Copies of this report may be obtained by calling NTSB's Public Inquiry Office at 202-314-6551, or on the NTSB website at www.ntsb.gov.

In the fourth paragraph under SUPPLEMENTARY INFORMATION, the first sentence reads:

The NTSB report suggests that .... Remove the word ``suggests'' and replace with the word ``states''.

In the fourth paragraph under Supplementary Information, the third sentence reads:

NTSB alleges that .... Remove the word ``alleges'' and replace with the word ``concluded''.

Under II. Advisory Bulletin (ADB-02-7) of the SUPPLEMENTARY INFORMATION heading, in the second paragraph under Advisory. The fourth sentence reads:

These older polyethylene pipe materials include the following:

The sentence is revised to read as follows:

These older polyethylene pipe materials include, but are not limited to:

Issued in Washington, DC on November 27, 2002.
James K. O'Steen,
Deputy Associate Administrator for Pipeline Safety.
[FR Doc. 02-30615 Filed 12-2-02; 8:45 am]

BILLING CODE 4910-60-P

Advisory Bulletin ADB-99-01

[Notices] [Page 12211-12212]

DEPARTMENT OF TRANSPORTATION
Research and Special Programs Administration

Potential Failure Due to Brittle-Like Cracking Certain Polyethylene Plastic Pipe Manufactured by Century Utility Products Inc

AGENCY: Research and Special Programs Administration (RSPA), DOT.

ACTION: Notice; issuance of advisory bulletin on Century polyethylene gas pipe to owners and operators of natural gas distribution systems.

SUMMARY: This advisory bulletin is directed at owners and operators of natural gas distribution systems that have installed plastic pipe extruded by Century Utility Products Inc. from Union Carbide Corporation's DHDA 2077 Tan medium density polyethylene resin (Century pipe). Pipe manufactured between 1970 and 1973 may fail in service due to its poor resistance to brittle-like cracking. Operators with Century pipe in their systems should closely monitor this pipe for leaks with increased leak survey frequency. Century pipe that may be improperly installed, repaired, or operating in an environment that impairs pipe strength should be replaced.

ADDRESSES: This document can be viewed on the Office of Pipeline Safety (OPS) home page at: http://ops.dot.gov.

FOR FURTHER INFORMATION CONTACT: Gopala (Krishna) Vinjamuri at (202) 366-4503, or by E-mail at vinjamuri@rspa.dot.gov.

SUPPLEMENTARY INFORMATION:
I. Background

The National Transportation Safety Board (NTSB) recently published the results of a special investigation into accidents that involved plastic pipe currently in use to deliver natural gas to residential and business use. The report, Brittle-Like Cracking in Plastic Pipe for Gas Service (NTSB/SIR-98/01; April 23, 1998) suggested that "[d]espite the general acceptance of plastic piping as a safe and economical alternative to piping made of steel and other materials, [a] number of pipeline accidents investigated have involved plastic piping that cracked in a brittle-like manner." Copies of this report may be obtained from NTSB Public Inquiry Office by calling 202-314-6551.

The phenomenon of brittle-like cracking in plastic pipe as described in the NTSB report and generally understood within the plastic pipeline industry relates to a part-through crack initiation in the pipe wall followed by stable crack growth at stress levels much lower than the stress required for yielding, resulting in a very tight slit-like opening and gas leak. This failure mode is difficult to detect until significant amount of gas leaks out of the pipe, and potentially migrates into closed space such as basements of dwellings. Premature brittle-like cracking requires relatively high localized stress intensification that may be a result from geometrical discontinuities, excessive bending, improper fitting assemblies, and/or dents and gouges. Because this failure mode exhibits no evidence of gross yielding at the failure location, the term brittle-like cracking is used. This phenomenon is different from brittle fracture, in which the failure results in fragmentation of the pipe.

NTSB also alleged that the guidance provided by manufacturers and industry standards for the installation of plastic pipe is inadequate for limiting stress intensification, particularly at plastic service connections to steel mains, many of these connections may have been installed without adequate protection from shear and bending forces that may result in brittle-like cracking.

Century Pipe

Between 1970 and 1973, Century Utility Products Inc. (a/k/a AMDEVCO), now defunct, marketed medium density polyethylene plastic pipe and fittings (Century pipe) in sizes ranging from \1/2\ inch to 4 inches for use in natural gas distribution. These plastic pipes and fittings were manufactured by extrusion from Union Carbide Corporation's DHDA 2077 Tan resin, and was marked PE 2306 in accordance with American Society for Testing and Materials (ASTM) standards. Following investigation of a series of incidents, including the December 2, 1979, explosion in a residence in Tuscola, Illinois, and the October 17, 1994, accident in Waterloo, Iowa, that resulted in several fatalities, it was established that the Union Carbide's DHDA 2077 Tan resin lacks adequate resistance to brittle-like cracking and is prone to relatively short life when subjected to high local stress concentration. The pipe in the Tuscola, Illinois, accident failed in less than 8 years, and the pipe in the Waterloo, Iowa, accident failed within 23 years in service. It has been established that Century pipe exhibited significantly higher leak rate in comparison with other polyethylene, steel, and cast iron pipe used in natural gas distribution systems.

Following the Waterloo, Iowa, accident, RSPA has taken number of actions, including gathering Century pipe installation data. Also, remedial action has been taken by various operators in mid-western states where much of the Century pipe produced was known to have been installed. It is RSPA's understanding that the operators having Century pipe in their systems have initiated close monitoring and some have replacement program in progress.

NTSB recommended that RSPA notify owners and operators of natural gas systems who continue to use Century pipe of the potential for premature failures by brittle-like cracking and the need to "[d]evelop a plan to closely monitor the performance of and to identify and replace, in a timely manner, any piping that indicates poor performance based on such evaluation factors as installation, operating and environmental conditions, piping failure characteristics and leak history."

II. Advisory Bulletin (ADB-99-01)

To: Owners and Operators of Natural Gas Distribution Pipeline Systems.

Subject: Susceptibility of certain polyethylene pipe manufactured by Century Utility Products Inc. to premature failure due to brittle-like cracking.

Purpose: To advise natural gas distribution pipeline owners and operators of the need to closely monitor and replace as necessary polyethylene natural gas pipe manufactured by Century Utility Products Inc. between 1970 and 1973 that is susceptible to brittle-like cracking.

Advisory: All owners and operators of natural gas distribution systems who have installed and continue to use polyethylene pipe extruded by Century Utility Products Inc, (now defunct) from the resin DHDA 2077 Tan resin manufactured by Union Carbide Corporation during the period 1970 to 1973 (Century pipe) are advised that this pipe may be susceptible to premature failure due to brittle-like cracking. Premature failures by brittle-like cracking of Century pipe is known to occur due to poor resin characteristics, excessive local stress intensification caused by improper joints, improper installation, and environments detrimental to pipe long-term strength. All distribution systems containing Century pipe should be monitored to identify pipe subject to brittle-like cracking. Remedial action, including replacement, should be taken to protect system integrity and public safety.

In addition, in light of the potential susceptibility of Century pipe to brittle-like cracking, RSPA recommends that each natural gas distribution system operator with Century pipe revise their plastic pipe repair procedure(s) to exclude pipe pinching for isolating sections of Century pipe. Additionally, RSPA recommends replacement of any Century pipe segment that has a significant leak history or which for any reason is of suspect integrity.

Authority: 49 U.S.C. Chapter 601; 49 CFR 1.53.

Issued in Washington, DC on March 5, 1999.
Richard B. Felder,
Associate Administrator for Pipeline Safety.
[FR Doc. 99-6013 Filed 3-10-99; 8:45 am]
BILLING CODE 4910-60-P

Advisory Bulletin ADB-99-02

[Notices][Page 12212-12213]

DEPARTMENT OF TRANSPORTATION
Research and Special Programs Administration

Potential Failures Due to Brittle-Like Cracking of Older Plastic Pipe in Natural Gas Distribution Systems

AGENCY: Research and Special Programs Administration (RSPA), DOT.

ACTION: Notice; issuance of advisory bulletin on brittle-like failures of plastic pipe to owners and operators of natural gas distribution systems.

SUMMARY: RSPA is issuing this advisory bulletin to owners and operators of natural gas distribution systems to inform them of the potential vulnerability of older plastic gas distribution pipe to brittle-like cracking. The National Transportation Safety Board (NTSB) recently issued a Special Investigation Report (NTSB/SIR-98/01), Brittle-like Cracking in Plastic Pipe for Gas Service, that described how plastic pipe installed in natural gas distribution systems from the 1960s through the early 1980s may be vulnerable to brittle-like cracking resulting in gas leakage and potential hazards to the public and property. RSPA has also issued an additional advisory bulletin (ADB-99-01) reminding natural gas distribution system operators of the potential poor resistance to brittle-like cracking of certain polyethylene pipe manufactured by Century Utility Products, Inc.

ADDRESSES: This document can be viewed on the Office of Pipeline Safety (OPS) home page at: http://ops.dot.gov.

FOR FURTHER INFORMATION CONTACT: Gopala K. Vinjamuri, (202) 366-4503, or by email at gopala.vinjamuri@rspa.dot.gov.

SUPPLEMENTARY INFORMATION:
I. Background

The National Transportation Safety Board (NTSB) recently issued a Special Investigation Report (NTSB/SIR-98/01), Brittle-like Cracking in Plastic Pipe for Gas Service, that described how plastic pipe installed in natural gas distribution systems from the 1960s through the early 1980s may be vulnerable to brittle-like cracking resulting in gas leakage and potential hazards to the public and property. An NTSB survey of the accident history of plastic pipe suggested that the material may be susceptible to premature brittle-like cracking under conditions of local stress intensification because of improper joining or installation procedures. Hundreds of thousands of miles of plastic pipe have been installed, with a significant amount installed prior to the mid-1980s. NTSB believes any vulnerability of this material to premature failure could represent a potentially serious hazard to public safety.

The NTSB report addressed the following safety issues:

· The vulnerability of plastic pipe to premature failures due to brittle-like cracking;

· The adequacy of available guidance relating to the installation and protection of plastic pipe connections to steel mains; and

· Performance monitoring of plastic pipeline systems as a way of detecting unacceptable performance in piping systems.

Copies of this report may be obtained by calling NTSB's Public Inquiry Office at 202-314-6551.

The phenomenon of brittle-like cracking in plastic pipe as described in the NTSB report and generally understood within the plastic pipeline industry relates to a part-through crack initiation in the pipe wall followed by stable crack growth at stress levels much lower than the stress required for yielding, resulting in a very tight slit-like opening and gas leak. Although significant cracking may occur at points of stress concentration and near improperly designed or installed fittings, small brittle-like cracks may be difficult to detect until a significant amount of gas leaks out of the pipe, and potentially migrates into an enclosed space such as a basement. Premature brittle-like cracking requires relatively high localized stress intensification that may be a result from geometrical discontinuities, excessive bending, improper fitting assemblies, and/or dents and gouges. Because this failure mode exhibits no evidence of gross yielding at the failure location, the term brittle-like cracking is used. This phenomenon is different from brittle fracture, in which the failure results in fragmentation of the pipe.

The report suggests that the combination of more durable plastic pipe materials and more realistic strength testing has improved the reliability of estimates of the long-term hydrostatic strength of modern plastic pipe and fittings. The report also documents that older polyethylene pipe, manufactured from the 1960s through the early 1980s, may fail at lower stresses and after less time than was originally projected. NTSB alleges that past standards used to rate the long-term strength of plastic pipe may have overrated the strength and resistance to brittle-like cracking of much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s.

In 1998, NTSB made several recommendations to trade organizations and to the Research and Special Programs Administration (RSPA) on the need for a better understanding of the susceptibility of plastic pipe to brittle-like cracking. NTSB recommended that RSPA "[d]etermine the extent of the susceptibility to premature brittle-like cracking of older plastic piping (beyond that marketed by Century Utilities Products Inc.) that remains in use for gas service nationwide."

II. Advisory Bulletin (ADB-99-02)

To: Owners and Operators of and Natural Gas Distribution Pipeline Systems

Subject: Potential susceptibility of plastic pipe installed between the 1960 and the early 1980s to premature failure due to brittle-like cracking.

Purpose: To inform natural gas distribution pipeline operators of the need to determine the extent of susceptibility to brittle-like cracking of plastic pipe installed between the years 1960 and early 1980s.

Advisory: A review of Office of Pipeline Safety (OPS) reportable natural gas pipeline incidents and the findings of NTSB Special Investigation Report (NTSB/SIR-98/01) indicates that certain plastic pipe used in natural gas distribution service may be susceptible to brittle-like cracking. The standards used to rate the long-term strength of plastic pipe may have overrated the strength and resistance to brittle-like cracking of much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s.

It is recommended that all owners and operators of natural gas distribution systems identify all pre-1982 plastic pipe installations, analyze leak histories, and evaluate any conditions that may impose high stresses on the pipe. Appropriate remedial action, including replacement, should be taken to mitigate any risks to public safety.

Authority: 49 U.S.C. Chapter 601; 49 CFR 1.53.
Issued in Washington, D.C. on March 3, 1999.
Richard B. Felder,
Associate Administrator for Pipeline Safety.

[FR Doc. 99-6051 Filed 3-10-99; 8:45 am]
BILLING CODE 4910-60-P

Proposed Protocol for Managing Select Aldyl A Pipe in Avista Utilities' Natural Gas System

Attachment 6

September 6, 2007
Federal Register Vol. 72, No. 172
Pipeline Safety: Updated Notification of the Susceptibility to Premature Brittle-Like Cracking of Older Plastic Pipe

safety procedures used for filling, operating, and discharging MATs to determine whether additional safety procedures should be implemented. To this end, we request that persons who use such transportation systems to provide us with information on the effectiveness of the current DOT regulations, consensus standards, and industry best practices. We are also interested in any other procedures utilized to ensure that operations related to the transportation of acetylene on MATs are performed safely.

We would also like to work with shippers, carriers, and facilities that receive shipments of acetylene in MATs to develop and implement a pilot program to test the effectiveness of current or alternative procedures or methods designed to enhance the safety of transportation operations involving acetylene on MATs. As part of this program, we will assist individual companies or facilities to evaluate the effectiveness of their current procedures and to identify additional measures that should be implemented. We welcome suggestions concerning how such a program should be structured and the entities that should participate.

To ensure that our message reaches all stakeholders affected by these risks, we plan to communicate this advisory through our public affairs notification and outreach processes. For additional visibility, we have made this advisory available on the PHMSA homepage at *http://www.phmsa.dot.gov* and the DOT electronic docket site at *http://dms.dot.gov*. In addition, if you are aware of other companies that are involved in the charging, operating, and discharging MATs, please share this advisory notice with them and, if possible, identify them in your correspondence with this agency. We believe a collaborative effort involving an integrated and cooperative approach will help us to address safety risks, reduce incidents, enhance safety, and protect the public.

Issued in Washington, DC on August 30, 2007.

Theodore L. Willke,

Associate Administrator for Hazardous Materials Safety.

[FR Doc. 07–4355 Filed 9–5–07; 8:45 am]

BILLING CODE 4910–60–P

DEPARTMENT OF TRANSPORTATION

Pipeline and Hazardous Materials Safety Administration

[Docket No. PHMSA–2004–19856]

Pipeline Safety: Updated Notification of the Susceptibility to Premature Brittle-Like Cracking of Older Plastic Pipe

AGENCY: Pipeline and Hazardous Materials Safety Administration (PHMSA); DOT.

ACTION: Notice; Issuance of Advisory Bulletin.

SUMMARY: PHMSA is issuing this updated advisory bulletin to owners and operators of natural gas pipeline distribution systems concerning the susceptibility of older plastic pipe to premature brittle-like cracking. PHMSA previously issued three advisory bulletins on this subject: Two on March 11, 1999 and one on November 26, 2002. This advisory bulletin expands on the information provided in the three prior bulletins by listing two additional pipe materials with poor performance histories relative to brittle-like cracking and by updating pipeline owners and operators on the ongoing voluntary efforts to collect and analyze data on plastic pipe performance. Owners and operators of natural gas pipeline distribution systems are encouraged to review the three previous advisory bulletins in their entirety.

FOR FURTHER INFORMATION CONTACT: Richard Sanders at (405) 954–7214, or by e-mail at *richard.sanders@dot.gov.*

SUPPLEMENTARY INFORMATION:

I. National Transportation Safety Board (NTSB) Investigation

On April 23, 1998, the National Transportation Safety Board (NTSB) issued its Special Investigation Report, *Brittle-Like Cracking in Plastic Pipe for Gas Service,* NTSB/SIR–98/01. The report described the results of the NTSB's special investigation of polyethylene gas service pipe, which addressed three major safety issues: (1) Vulnerability of plastic piping to premature failures due to brittle-like cracking; (2) adequacy of available guidance relating to the installation and protection of plastic piping connections to steel mains; and, (3) effectiveness of performance monitoring of plastic pipeline systems to detect unacceptable performance in piping systems.

(1) *Vulnerability of plastic piping to premature failures due to brittle-like cracking:* The NTSB found that failures in polyethylene pipe in actual service are frequently brittle-like, slit failures, not ductile failures. It concluded the number and similarity of plastic pipe accident and non-accident failures indicate past standards used to rate the long-term strength of plastic pipe may have overrated the strength and resistance to brittle-like cracking for much of the plastic pipe manufactured and used for gas service from the 1960s through the early 1980s. The NTSB also concluded any potential public safety hazards from these failures are likely to be limited to locations where stress intensification exists. The NTSB went on to state that more durable modern plastic piping materials and better strength testing have made the strength ratings of modern plastic piping more reliable.

(2) *Adequacy of available guidance relating to the installation and protection of plastic piping connections to steel mains:* The NTSB concluded that gas pipeline operators had insufficient notification of the brittle-like failure potential for plastic pipe manufactured and used for gas service from the 1960s to the early 1980s. The NTSB also concluded this may not have allowed companies to implement adequate surveillance and replacement programs for older plastic piping. The NTSB explained the Gas Research Institute (GRI) developed a significant amount of data on older plastic pipe but the data was published in codified terms making it insufficient for use by pipeline system operators. The NTSB recommended that manufacturers of resin and pipe, industry trade groups and the Federal government do more to alert pipeline operators to the role played by stress intensification from external forces in the premature failure of plastic pipe due to brittle-like cracking.

(3) *Effectiveness of performance monitoring of plastic pipeline systems as a way of detecting unacceptable performance in piping systems:* The NTSB's analysis noted that Federal regulations require pipeline operators to have an ongoing program to monitor the performance of their pipeline systems. However, the NTSB investigation revealed some gas pipeline operators' performance monitoring programs did not effectively collect and analyze data to determine the extent of possible hazards associated with plastic pipeline systems. The NTSB pointed out, ''such a program must be adequate to detect trends as well as to identify localized problem areas, and it must be able to relate poor performance to specific factors such as plastic piping brands, dates of manufacture (or installation dates), and failure conditions.''

Copies of this report may be obtained by searching the NTSB Web site at *www.ntsb.gov.*

II. Advisory Bulletins Previously Issued by PHMSA

The NTSB made several recommendations to PHMSA and to trade organizations in its 1998 special investigation report. In response, PHMSA issued three advisory bulletins. The first advisory bulletin, ADB–99–01, *Potential Failure Due to Brittle-Like Cracking of Certain Polyethylene Plastic Pipe Manufactured by Century Utility Products Inc,* was published in the **Federal Register** (FR) on March 11, 1999 (64 FR 12211) to advise natural gas pipeline distribution system operators that brittle-like cracking may occur on certain polyethylene pipe manufactured by Century Utility Products, Inc.

The second advisory bulletin, ADB–99–02, *Potential Failures Due to Brittle-Like Cracking of Older Plastic Pipe in Natural Gas Distribution Systems,* was also published in the **Federal Register** on March 11, 1999 (64 FR 12212) to advise natural gas pipeline distribution system operators of the potential for brittle-like cracking of plastic pipes installed between the 1960s and early 1980s.

The third advisory bulletin, ADB–02–07, *Notification of the Susceptibility To Premature Brittle-Like Cracking of Older Plastic Pipe,* was published in the **Federal Register** on November 26, 2002 (67 FR 70806) to reiterate to natural gas pipeline distribution system operators the susceptibility of older plastic pipe to premature brittle-like cracking. The older polyethylene pipe materials specifically identified in ADB–02–07 included, but were not limited to:

- Century Utility Products, Inc. products;
- Low-ductile inner wall ''Aldyl A'' piping manufactured by DuPont Company before 1973; and
- Polyethylene gas pipe designated PE 3306.

This third advisory bulletin also listed several environmental, installation and service conditions in which plastic piping is used that could lead to premature brittle-like cracking failure. PHMSA also described six recommended practices for polyethylene gas pipeline system operators to aid them with identifying and managing brittle-like cracking problems.

III. Plastic Pipe Studies

Beginning January 25, 2001, the American Gas Association (AGA) began to collect data on in-service plastic piping material failures with the objective of identifying trends in the performance of these materials. The resulting leak survey data, collected from 2001 to present, on the county's natural gas distribution systems includes both actual failure information and negative reports (reports of no leads) submitted voluntarily by participating pipeline operating companies.

The AGA, PHMSA, and other industry and state organizations continue to collect and analyze the data. Unfortunately, the data cannot be correlated with the quantities of each plastic pipe material that may be in service across the United States. Therefore, the data does not assess the failure rates of individual plastic pipe materials on a linear basis (i.e. per foot, per mile, etc.). However, the failure data reinforces what is historically known about certain older plastic piping and components. The data also indicates the susceptibility of additional specific materials to brittle-like cracking.

IV. Advisory Bulletin ADB–07–01

To: Owners and Operators of Natural Gas Pipeline Distribution Systems.

Subject: Updated Notification of the Susceptibility of Older Plastic Pipes to Premature Brittle-Like Cracking.

Advisory: All owners and operators of natural gas distribution systems who have installed and operate plastic piping are reminded of the phenomenon of brittle-like cracking. Brittle-like cracking refers to crack initiation in the pipe wall not immediately resulting in a full break followed by stable crack growth at stress levels much lower than the stress required for yielding. This results in very tight, slit-like, openings and gas leaks. Although significant cracking may occur at points of stress concentration and near improperly designed or installed fittings, small brittle-like cracks may be difficult to detect until a significant amount of gas leaks out of the pipe, and potentially migrates into an enclosed space such as a basement. Premature brittle-like cracking requires relatively high localized stress intensification that may result from geometrical discontinuities, excessive bending, improper installation of fittings, dents and/or gouges. Because this failure mode exhibits no evidence of gross yielding at the failure location, the term brittle-like cracking is used. This phenomenon is different from brittle fracture, in which the pipe failure causes fragmentation of the pipe.

All owners and operators of natural gas distribution systems are future advised to review the three earlier advisory bulletins on this issue. In addition to being available in the **Federal Register**, these advisory bulletins are available in the docket, and on PHMSA's Web site at *http://phmsa.dot.gov/* under Pipeline Safety Regulations.

In the first advisory bulletin, ADB–99–01, published on March 11, 1999 (64 FR 12211), PHMSA advises natural gas distribution system operators of the potential for poor resistance to brittle-like cracking of certain polyethylene pipe manufactured by Century Utility Products, Inc. In the second advisory bulletin, ADB–99–02, published on March 11, 1999 (64 FR 12212), PHMSA advises natural gas distribution system operators of the potential for brittle-like cracking of plastic pipes installed between the 1960s and early 1980s.

In the third advisory bulletin, ADB–02–07, published on November 26, 2002 (67 FR 70806), PHMSA reiterates to pipeline operators the susceptibility of some older plastic pipe to premature brittle-like cracking which could substantially reduce the service life of natural gas distribution systems and to explain the mission of the Plastic Pipe Database Committee (PPDC) ''to develop and maintain a voluntary data collection process that supports the analysis of the frequency and causes of in-service plastic piping material failures.'' The advisory bulletin also lists several environmental, installation and service conditions under which plastic piping is used which is used which could lead to premature brittle-like cracking failure. PHMSA also describes six recommended practices for polyethylene gas pipeline system operators to aid them with identifying and managing brittle-like cracking problems.

Lastly, the susceptibility of some polyethylene pipes to brittle-like cracking is dependent on the resin, pipe processing, and service conditions. As noted in ADB–02–07, these older polyethylene pipe materials include, but are not limited to:

- Century Utility Products, Inc. products;
- Low-ductile inner wall ''Aldyl A'' piping manufactured by DuPont Company before 1973; and
- Polyethylene gas pipe designated PE 3306.

The data now supports adding the following pipe materials to this list:

- Delrin insert tap tees; and,
- Plexco service tee Celcon (polyacetal) caps.

Authority: 49 U.S.C. chapter 601 and 49 CFR 1.53.

Issued in Washington, DC, on August 28, 2007.

Jeffrey D. Wiese,

Associate Administrator for Pipeline Safety.

[FR Doc. 07–4309 Filed 9–5–07; 8:45 am]

BILLING CODE 4910–60–M

DEPARTMENT OF TRANSPORTATION

Pipeline and Hazardous Materials Safety Administration

[Docket No. PHMSA–2007–28993]

Pipeline Safety: Adequacy of Internal Corrosion Regulations for Hazardous Liquid Pipelines

AGENCY: Pipeline and Hazardous Materials Safety Administration (PHMSA), U.S. Department of Transportation (DOT).

ACTION: Notice of availability of materials; request for comments.

SUMMARY: This notice announces the availability of materials, including a briefing paper prepared for PHMSA's Technical Hazardous Liquid Pipeline Safety Standards Committee (THLPSSC) and data on risks posed by internal corrosion on hazardous liquid pipelines. PHMSA is preparing a report to Congress on the adequacy of the internal corrosion regulations for hazardous liquid pipelines. Participants at a meeting of the THLPSSC discussed issues involved in examining the adequacy of the regulations and requested additional data. PHMSA requests public comment on these matters.

DATES: Submit comments by October 9, 2007.

ADDRESSES: Comments should reference Docket No. PHMSA–2007–28993 and may be submitted in the following ways:

- *E-Gov Web site: http://www.regulations.gov.* This Web site allows the public to enter comments on any **Federal Register** notice issued by any agency. Follow the instructions for submitting comments.
- *Fax:* 1–202–493–2251.
- *Mail:* Docket Management System: U.S. Department of Transportation, Docket Operations, M–30, Room W12–140, 1200 New Jersey Avenue, SE., Washington, DC 20590–0001.
- *Hand Delivery:* DOT Docket Management System, West Building Ground Floor, Room W12–140, 1200 New Jersey Avenue, SE., Washington, DC 20590–0001 between 9 a.m. and 5 p.m., Monday through Friday, except Federal holidays.

Instructions: Identify the docket number, PHMSA–2007–28993, at the beginning of your comments. If you submit your comments by mail, submit two copies. To receive confirmation that PHMSA received your comments, include a self-addressed stamped postcard. Internet users may submit comments at *http://www.regulations.gov.*

Note: Comments are posted without changes or edits to *http://www.regulations.gov*, including any personal information provided. There is a privacy statement published on *http://www.regulations.gov.*

FOR FURTHER INFORMATION CONTACT: Barbara Betsock at (202) 366–4361, or by e-mail at *barbara.betsock@dot.gov.*

SUPPLEMENTARY INFORMATION: The Pipeline Inspection, Protection, Enforcement, and Safety Act of 2006 directs PHMSA to review the internal corrosion regulations in subpart H of 49 CFR part 195 to determine if they are adequate to ensure adequate protection of the public and environment and to report to Congress on the results of the review. As an initial step in the review, PHMSA consulted the THLPSSC at its meeting on July 24, 2007. The briefing paper prepared for the committee members contains preliminary data on risk history as well as questions relating to the internal corrosion regulations. This briefing paper is posted on PHMSA's pipeline Web site (*http://ops.dot.gov*) and has been placed in the docket.

At the meeting, PHMSA officials committed to gathering additional data responding to questions posed by the committee members. PHMSA has updated the data and included data responsive to the committee members. This data is also posted on the pipeline Web site and contained in the docket.

PHMSA requests comments on the adequacy of the internal corrosion regulations and answers to the questions posed in the briefing paper. PHMSA will use these comments in its review of the internal corrosion regulations.

Authority: 49 U.S.C. 60102, 60115, 60117: Sec. 22, Pub. L. 109–468, 120 Stat. 3499.

Issued in Washington, DC on August 27, 2007.

Jeffrey D. Wiese,

Associate Administrator for Pipeline Safety.

[FR Doc. E7–17538 Filed 9–5–07; 8:45 am]

BILLING CODE 4910–60–P

DEPARTMENT OF VETERANS AFFAIRS

[OMB Control No. 2900–0675]

Proposed Information Collection Activity: Proposed Collection; Comment Request

AGENCY: Center for Veterans Enterprise, Department of Veterans Affairs.

ACTION: Notice.

SUMMARY: The Center for Veterans Enterprise (CVE), Department of Veterans Affairs (VA), is announcing an opportunity for public comment on the proposed collection of certain information by the agency. Under the Paperwork Reduction Act (PRA) of 1995, Federal agencies are required to publish notice in the **Federal Register** concerning each proposed collection of information, including each proposed extension of a currently approved collection, and allow 60 days for public comment in response to the notice. This notice solicits comments for information needed to identify veteran-owned businesses.

DATES: Written comments and recommendations on the proposed collection of information should be received on or before November 5, 2007.

ADDRESSES: Submit written comments on the collection of information through *http://www.Regulations.gov;* or Gail Wegner (00VE), Department of Veterans Affairs, 810 Vermont Avenue, NW., Washington, DC 20420 or e-mail: *gail.wegner@va.gov.* Please refer to ''OMB Control No. 2900–0675'' in any correspondence. During the comment period, comments may be viewed online through the Federal Docket Management System (FDMS) at *http://www.Regulations.gov.*

FOR FURTHER INFORMATION CONTACT: Gail Wegner at (202) 303–3296 or FAX (202) 254–0238.

SUPPLEMENTARY INFORMATION: Under the PRA of 1995 (Pub. L. 104–13; 44 U.S.C. 3501–3521), Federal agencies must obtain approval from the Office of Management and Budget (OMB) for each collection of information they conduct or sponsor. This request for comment is being made pursuant to section 3506(c)(2)(A) of the PRA.

With respect to the following collection of information, CVE invites comments on: (1) Whether the proposed collection of information is necessary for the proper performance of CVE's functions, including whether the information will have practical utility; (2) the accuracy of CVE's estimate of the burden of the proposed collection of

Proposed Protocol for Managing Select Aldyl A Pipe in Avista Utilities' Natural Gas System

Attachment 7

U.S. Department of Transportation Call to Action To Improve the Safety of the Nation's Energy Pipeline System

U.S. Department of Transportation Call to Action
To Improve the Safety of the Nation's Energy Pipeline System

Executive Summary

Today, more than 2.5 million miles of pipelines are responsible for delivering oil and gas to communities and businesses across the United States. That's enough pipeline to circle the earth approximately 100 times.

Currently, these liquid and gas pipelines are operated by approximately 3,000 companies and fall under the safety regulations of the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA). PHMSA has engineers and inspectors around the country who oversee the safety of these lines and ensure that companies comply with critical safety rules that protect people and the environment from potential dangers. While PHMSA directly regulates most of the hazardous liquid pipelines in the nation, states take over when it comes to intrastate natural gas pipelines. Every state, except Hawaii and Alaska,is responsible for the inspection and enforcement of state pipeline safety laws for the natural gas pipeline systems within their respective state. Some states – about 20 percent - also regulate the hazardous liquid lines within state borders.

In the wake of several recent serious pipeline incidents, U.S. DOT/PHMSA is taking a hard look at the safety of the nation's pipeline system. Over the last three years, annual fatalities have risen from nine in 2008, to 13 in 2009 to 22 in 2010. Like other aspects of America's transportation infrastructure, the pipeline system is aging and needs a comprehensive evaluation of its fitness for service. Investments that are made now will ensure the safety of the American people and the integrity of the pipeline infrastructure for future generations.

For these reasons, Secretary LaHood is issuing a call to action for all pipeline stakeholders, including the pipeline industry, the utility regulators, and our state and federal partners. Secretary LaHood brought together PHMSA Administrator Quarterman and the senior DOT leadership to design a strategy to achieve that goal. The action plan below is the result of those deliberations.

Background

Much of the nation's pipeline infrastructure was installed many decades ago, and some century-old infrastructure continues to transport energy supplies to residential and commercial customers, particularly in the urban areas across our nation. Older pipeline facilities that are constructed of obsolete materials (e.g., cast iron, copper, bare steel, and certain kinds of welded pipe) may have degraded over time, and some have been exposed to additional threats, such as excavation damage.

On December 4, 2009, PHMSA issued the Distribution Integrity Management Final Rule, which extends the pipeline integrity management principles that were established for hazardous liquid and natural gas transmission pipelines, to the local natural gas distribution pipeline systems. This regulation, which becomes effective in August of 2011, requires operators of local gas distribution pipelines to evaluate the risks on their pipeline systems to determine their fitness for service and take action to address those risks. For older gas distribution systems, the appropriate mitigation measures could involve major pipe rehabilitation, repair, and replacement programs. At a minimum, these measures are needed to requalify those systems as being fit for service. While these measures may be costly, they are necessary to address the threat to human life, property, and the environment.

In addition to the many pipelines constructed with obsolete materials, there are also early vintage steel pipelines in high consequence areas that may pose risks because of inferior materials, poor construction practices, lack of maintenance or inadequate risk assessments performed by operators. The lack of basic information or incomplete records about these systems is also a contributing factor. The U.S. DOT is seeking to make sure these risks are identified, the pipelines are assessed accurately, and preventative steps are taken where they are needed.

Action Plan

The U.S. DOT and PHMSA have developed this action plan to accelerate rehabilitation, repair, and replacement programs for high-risk pipeline infrastructure and to requalify that infrastructure as fit for service. The Department will engage pipeline safety stakeholders in the process to systematically address parts of the pipeline infrastructure that need attention, and ensure that Americans remain confident in the safety of their families, their homes, and their communities. The strategy involves:

- <u>A Call to Action</u> – Secretary LaHood is issuing a “Call to Action” to engage state partners, technical experts, and pipeline operators in identifying pipeline risks and repairing, rehabilitating, and replacing the highest risk infrastructure. Secretary LaHood is also asking Congress to expand PHMSA’s ability to oversee pipeline safety.
    - Secretary LaHood and PHMSA Administrator Quarterman have already met with the Federal Energy Regulatory Commission (FERC), the National Association of Regulatory and Utility Commissioners (NARUC), state public utility commissions, and industry leaders to ask all parties to step up efforts to identify high-risk pipelines and ensure that they are repaired or replaced.
    - Secretary LaHood is asking Congress to increase the maximum civil penalties for pipeline violations from $100,000 per day to $250,000 per day, and from $1 million for a series of violations to $2.5 million for a series of violations. He is also asking Congress to help close regulatory loopholes, strengthen risk management requirements, add more inspectors, and improve data reporting to help identify potential pipeline safety risks early.

  - The U.S. DOT and PHMSA are convening a Pipeline Safety Forum in April to engage in a working session around the actions that the Department, states, and industry can take to drive more aggressive actions to raise the bar on pipeline safety. The U.S. DOT and PHMSA will compile a report based on ideas, opportunities and challenges presented at the Forum and take action on solutions.

- Aggressive Efforts – The U.S. DOT and PHMSA are calling on pipeline operators and owners to review their pipelines and quickly repair and replace sections in poor condition.

  - PHMSA has asked technical associations and pipeline safety groups to provide best practices and technologies for repair, rehabilitation and replacement programs, and has asked industry groups for commitments to accelerate needed repairs.

  - PHMSA will review all data received from pipeline operators to identify areas with critical needs.

  - PHMSA's Distribution Integrity Management rule will become effective in August, requiring all operators of gas distribution pipelines to evaluate the risks on their pipeline systems and take action to address those risks.

- Transparency - U.S. DOT and PHMSA will execute this plan in a transparent manner with opportunity for public engagement, including a dedicated website for this initiative, and regular reporting to the public.

  - PHMSA will launch a public website with ongoing pipeline rehabilitation, replacement and repair initiatives.

  - All materials from the Pipeline Safety Forum will be publicly posted to the web, followed by a Draft Report for Notice and Comment. Once public input has been collected, PHMSA will publish a final Pipeline Safety Report to the Nation.

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Proposed Protocol for Managing Select Aldyl A Pipe in Avista Utilities' Natural Gas System

Attachment 8

Recommended Protocol For Avista Assessment of Aldyl 'A' and Other MDPE Pipes

Palermo Plastics Pipe (P³)
Consulting
Dr. Gene Palermo
www.plasticspipe.com

"Recommended Protocol For Avista Assessment of Aldyl 'A' and Other MDPE Pipes"

By

Dr. Gene Palermo
President
Palermo Plastics Pipe Consulting
www.plasticspipe.com

March 4, 2011

"Recommended Protocol For Avista Assessment of Aldyl 'A' and other MDPE Pipes"

I. Summary

As a result of the Agreement between Avista and the WS UTC that resulted from an Aldyl "A" rock impingement failure, Avista needs to assess the Aldyl "A" pipe in its gas distribution system along with the soil conditions. Avista requested assistance from Dr. Gene Palermo based on his experience with Aldyl "A" pipe.

In this report I have summarized the various Alathon MDPE (medium density polyethylene) resins that were used to produce Aldyl "A" pipe for natural gas distribution applications, and their respective resistance to slow crack growth (SCG) failure. In this report I have also described the Rate Process Method (RPM) and compared RPM projections to the resin SCG resistance and to the field performance for the various generations of Aldyl "A" pipe. Based on this information, I then proposed the following recommended protocol for Avista to use in assessing MDPE pipes in their gas distribution system. For the purposes of this report, when I use the term "pipe", I am referring to main pipe sizes, 1-1/4" IPS and larger. The smaller service tubing sizes are not an issue for rock impingement. Also, none of the Aldyl "A" service sizes (tubing sizes) had a low ductile inner wall (LDIW).

1) All Aldyl "A" pipe manufactured prior to 1984 should be evaluated for replacement.

a) If the pipe is LDIW (low ductile inner wall) Aldyl "A" pipe, Avista should start a prioritized pipe replacement program immediately.
b) If the Aldyl "A" pipe is installed in soil with rocks larger than ¾", Avista should start a prioritized pipe replacement program immediately.
c) If the Aldyl "A" pipe is installed in sandy soil or in soil with rocks up to ¾" in size, the pipe should remain in service and normal leak surveys per DOT Part 192 should be followed.

2) All Aldyl "A" pipe manufactured during or after 1984 and all yellow MDPE pipe, both PE 2406 and unimodal PE 2708, should also be evaluated.

a) If this pipe is installed in rocks larger than ¾" in size, Avista should evaluate the pipe and consider replacing it if they begin to experience rock impingement failures, and should conduct leak surveys more frequently than required by DOT Part 192, until replacement.
b) If this pipe is installed in sandy soil or in soil with rocks up to ¾" in size, the pipe should remain in service and normal leak surveys should be followed.

3) All bimodal PE 2708 pipe may be installed by Avista in any soil condition. Due to the very high SCG resistance of this pipe it is essentially immune to rock impingement failure.

This pipe is similar to bimodal PE 100 RC pipe that has been installed in Europe for the past five years in natural rocky backfill. This PE 100 RC material was developed in Europe so that gas companies could use “sandless” backfill, i.e. use the natural rocky backfill. The SCG resistance of bimodal PE 2708 is even greater than PE 100 RC.

II. Background – Dr. Palermo

Dr. Gene Palermo received a Bachelor of Science in Chemistry from St. Thomas College in St. Paul, MN in 1969 and a Ph.D. in Analytical Chemistry from Michigan State University in 1973.

Dr. Palermo has been in the plastic piping industry for over 35 years. He worked for the DuPont Company from 1976 to 1995 in the Aldyl “A” polyethylene (PE) pipe business for natural gas distribution. During that time, he was involved with research, manufacturing and marketing the Aldyl “A” piping system for natural gas applications. Dr. Palermo then developed the initial use of polyamide (PA) 11 for high-pressure gas distribution, up to 250 psig for SDR 11, to replace metal pipe while with Elf AtoChem during 1995 and 1996.

Dr. Palermo was the Technical Director for the Plastics Pipe Institute (PPI) from 1996 until 2003. As Technical Director, Dr. Palermo was chairman of the Hydrostatic Stress Board (HSB) on which he had served for over 20 years to develop pressure-rating methods for plastic pipe; and chairman of the Technical Advisory Group for ISO/TC 138 for international plastic piping systems. Dr. Palermo has developed standards for plastic pipe and fittings in several standards bodies; ASTM F17, CSA B137, AASHTO, and ISO/TC 138.

Most of Dr. Palermo’s expertise has been in the natural gas distribution industry. He has been a member of the AGA Plastic Materials Committee for over 25 years, the Gas Pipe Technology Committee for over 15 years, an instructor for the DOT inspector training school, and was an original member of the Plastic Pipe Database Committee. Dr. Palermo has also developed a one day Technical Seminar for the gas distribution industry.

Dr. Palermo currently serves as a member of PPI, AGA, GPTC (Chairman of Manufacturers Division), AWWA, ASTM F 17 (Director of Division I), ASTM D 20, CSA B137, CSA Z662 (Chairman of Clause 12 Gas Distribution), and ISO/TC 138. Dr. Palermo is currently president of his consulting firm – Palermo Plastics Pipe Consulting. Dr. Gene Palermo was recently honored with the **ASTM Award of Merit**, which is the highest Society recognition for individual contributions to standards activities, and the **AGA Platinum Award of Merit**, which is the highest award that can be achieved within AGA. Dr. Palermo is the only person to receive both of these very prestigious awards!

III. DuPont Aldyl "A" Resins

A. Alathon 5040

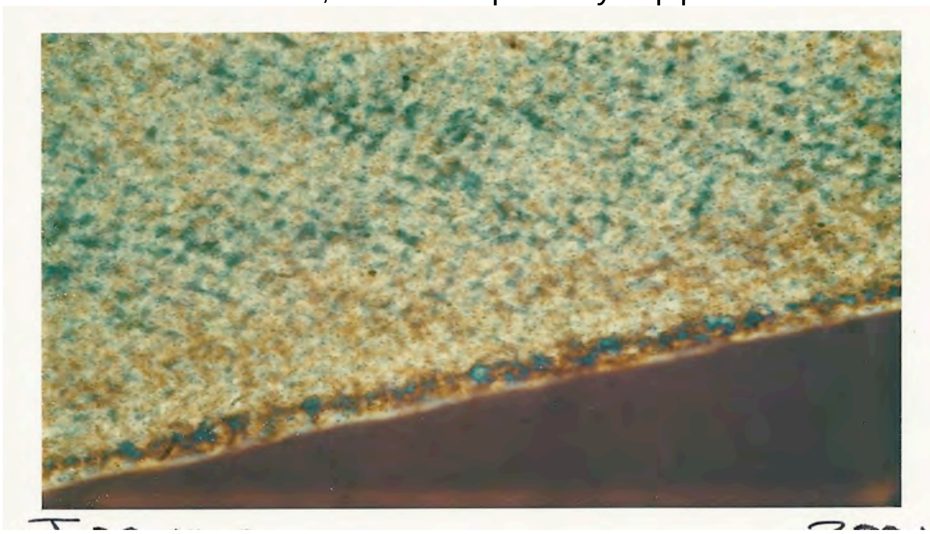
The PE resin that DuPont initially used for the production of Aldyl "A" pipe from 1965 to 1970 was Alathon 5040. This PE resin used a butene comonomer and had a base resin density of 0.935 g/cc and a melt index (MI) of 2.0 g/10 min. These two properties of melt index and density control many of the other physical properties for PE materials. Most of the other PE materials used for the gas industry at that time had an MI of about 0.2 g/10 min, so Aldyl "A" was not fusion compatible with these other PE materials. With this relatively low molecular weight (high MI), the recommended butt fusion temperature for Aldyl "A" pipe was 310ºF (154ºC), compared to 400ºF (204ºC) to 500ºF (260ºC) for the other PE materials. Aldyl "A" pipe installed by Avista between 1968 and 1970 was likely made from Alathon 5040 resin.

B. Alathon 5043

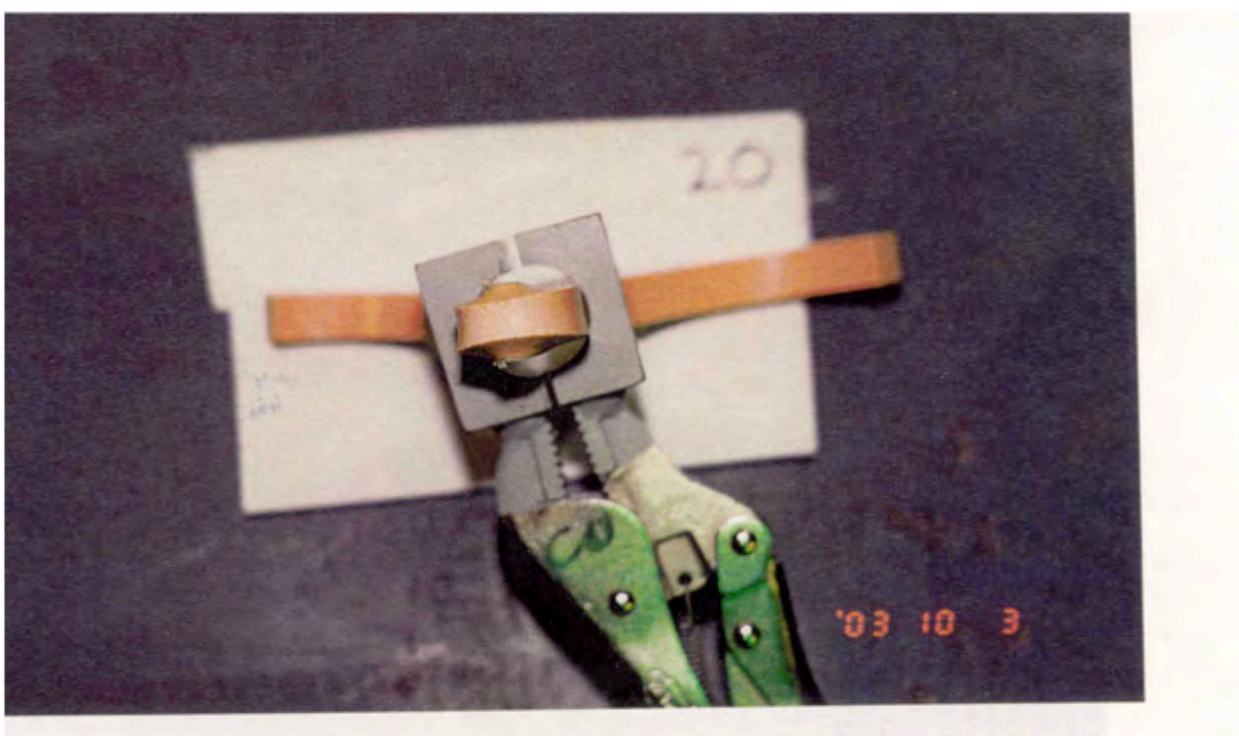
Because some of the small tubing sizes made from the Alathon 5040 resin did not consistently meet the ASTM D 1599 quick burst minimum stress requirement of 2520 psi, DuPont decided to use a higher density PE resin. DuPont changed to Alathon 5043 resin in 1970. This was also a butene comonomer, but with a higher base resin density of 0.939 g/cc to increase the yield strength and more consistently meet the quick burst stress requirements. In order to maintain a balance of molecular parameters, the molecular weight was increased when the density was increased, and the corresponding melt index was 1.2 g/10 min. With this higher molecular weight (lower MI) the butt fusion melt temperature was increased to 340ºF (171ºC).

Alathon 5043 was the primary PE resin that DuPont used for Aldyl "A" pipe from 1970 to 1984. It was also during this time that the LDIW (low ductile inner wall) phenomenon occurred. In the late 1970 through the 1971 era, DuPont had a manufacturing issue that resulted in a brittle inside surface. This was finally detected during some elevated temperature stress rupture testing that resulted in premature failures, in which multiple slits were observed as opposed to the normal single slit failure. It was also noted that the spherulites on the inside surface were very large (30 to 40 microns), as shown in the photo below. Because of these large spherulites on the inside surface, this pipe is called "large bore spherulite" pipe, or the term more commonly used is LDIW for "low ductile inner wall". The terms "low ductile inner wall" and "large bore spherulites" are synonymous. The brittle inside surface resulted from the manufacturing process that degraded the inner surface. The premature failures were due to an oxidized inner surface that dramatically reduced the initiation time and thus the overall failure time. The effect of this LDIW surface on long-term pipe performance has been determined using the Rate Process Method (RPM), which is discussed in Appendix A (this is a paper that I presented at the 2004 AGA Operations Conference). In early 1972 DuPont changed the manufacturing process to prevent these large spherulites from forming.

DuPont estimated that about 30% to 40% of the pipe it produced in 1970 and 1971 had an LDIW inner surface, and it was primarily in pipe sizes 1-1/4" to 4" IPS.



When Avista exhumes Aldyl "A" pipe manufactured during 1970 to 1972 (year codes F, G and H), they should first determine if it has an LDIW surface. This can be accomplished with a reverse bend test on a ½" strip of Aldyl "A" pipe. If the inside surface is smooth and shiny, then it is likely normal production Aldyl "A" pipe. If the inside surface has cracks or crazes, as shown in the photo below, then it is likely an LDIW inner surface.



C. Alathon 5046-C

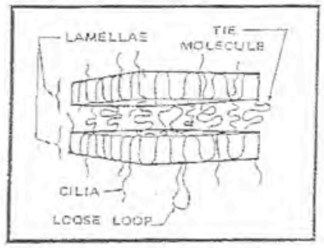
Around 1984 DuPont made a significant change in the PE resin as they switched from a butene comonomer to an octene comonomer. The original octene resin was called Alathon 5046-C, and it had a melt index of 1.1 g/10 min and a base resin density of 0.939 g/cc. This change to octene resulted in a significant improvement in slow crack growth (SCG) resistance and in long-term performance. The octene comonomer has longer side branches than butene (six carbons instead of two carbons), and this improved the efficiency of the tie molecules, which control long-term performance. This is explained in Figure 1. Polyethylene is known as a semi-crystalline polymer, meaning part of the polyethylene is in a crystalline region and part in an amorphous region. In the crystalline region, the molecules form crystals known as "lamellas" – this is also known as "folded chain morphology" for polyethylene, and these crystals are shown in the top photo of Figure 1. When a PE molecule exits the crystal and terminates, it is called a "cilia". When a PE molecule exits and returns to the same crystal it is called a "loose loop". When it exits and then enters another crystal it is called a "tie molecule". These are the long chain molecules that literally "tie" the crystals together. This combination of cilia, loose loops and tie molecules form the "amorphous" portion of PE.

When a high load is applied to PE, the failure that results is a short-term ductile failure; the crystals break apart as shown in the middle photo of Figure 1. These high load or high stress properties are the short-term properties, such as yield strength, and are dependant on the PE base resin density. When a lower load (stress) is applied to PE material the failure mode is a long-term slit or brittle failure. In this case, the amorphous region unravels as the lamellas separate. As they continue to separate, it is the tie molecules that hold these lamellas together, as shown in the bottom photo of Figure 1. When these tie molecules finally break, a crack forms and then advances or grows, which results in the long-term failure mode known as slow crack growth (SCG).

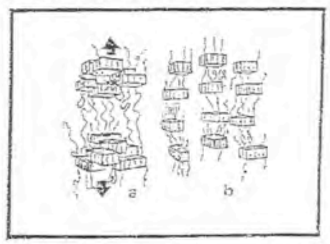
When the load is initially applied to the PE material, a craze zone forms at the tip of a small crack or an imperfection. This craze zone is due to the alignment of the tie molecules as the load is applied. Eventually, the tie molecules begin to break, and this causes the crack to grow to the end of the craze zone. At this point, the crack arrests (stops) and a new craze zone forms, and the process continues. The slow crack growth phenomenon thus consists of crack growth followed by crack arrest, then crack growth followed by crack arrest, etc. This growth/arrest pattern results in growth rings on a fracture surface, much like "tree rings" that form on a tree. These growth rings are very apparent in actual PE field failures due to slow crack growth, and they are also very apparent in elevated temperature stress rupture testing of PE pipe or fittings. The duplication of this crack/arrest failure mode in laboratory testing is the reason that prediction models, such as the Rate Process Method, are very good.

FIGURE 1

- POLYETHYLENE MOLECULES

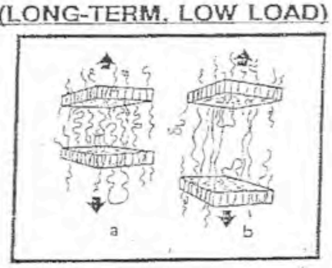


- DUCTILE FAILURE (SHORT-TERM, HIGH LOAD)



SHORT-TERM STRENGTH IS BASED ON DENSITY (CRYSTAL LATTICE INTEGRITY)

- SLIT FAILURE (LONG-TERM, LOW LOAD)

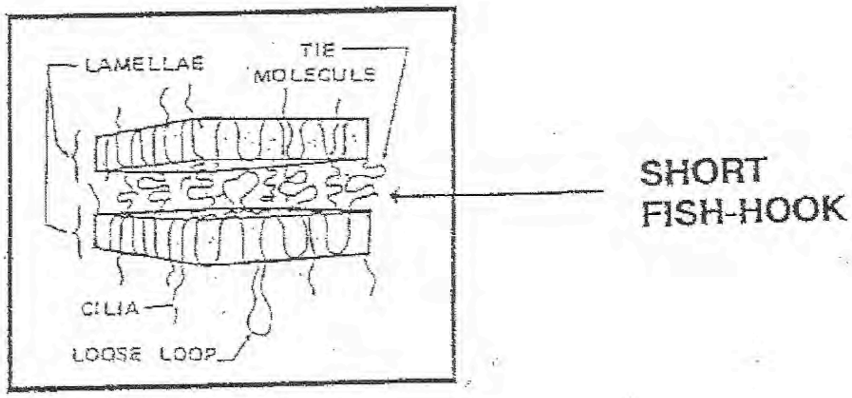


LONG-TERM STRENGTH IS BASED ON EFFICIENCY OF TIE-MOLECULES.

Figure 1 – Tie Molecules in Polyethylene

TIE MOLECULE EFFICIENCY

THE EFFICIENCY OF THE TIE MOLECULES IN KEEPING THE CRYSTAL LATTICES TOGETHER IS BASED ON THE COMONOMER, WHICH ACTS LIKE A "FISH-HOOK".



BY MODIFYING THE COMONOMER AND MAKING THE "FISH-HOOKS" LONGER, THE TIE MOLECULES ARE MORE EFFICIENT.

Figure 2 – Efficiency of Tie Molecules

With the butene comonomer, there are only two carbons as a side branch on the PE molecule, and these act as “short fish hooks” (Figure 2) in trying to prevent the tie molecule from unraveling. With the octene comonomer, there are now six carbons on the side branches, and these act as much longer fish hooks and are more efficient in preventing the tie molecules from unraveling. Since these longer fish hooks are more efficient in keeping the tie molecules from unraveling, it takes a longer time for the tie molecules to break. This increased efficiency of the tie molecules results in a significantly longer time for the crack to grow and thus for a failure to occur, as shown below in a typical 80ºC/120 psig stress rupture test for LDIW Aldyl “A” and Aldyl “A” pipe, using test method ASTM D 1598:

- LDIW - Alathon 5043 resin (butene comonomer) 10 hours
- Alathon 5043 resin (butene comonomer) 100 hours
- Alathon 5046C resin (octane comonomer) 1000 hours

There is an order of magnitude difference in the failure time between LDIW Aldyl "A" and normally produced Aldyl "A" pipe. There is also an order of magnitude difference in the failure time between the butene comonomer Alathon 5043 resin and the octane comonomer Alathon 5046C resin. With this improvement in long-term performance, DuPont called this new product Improved Aldyl "A". DuPont began production of Aldyl "A" pipe using Alathon 5046-C in 1984. Any pipe manufactured during 1984 or later is likely improved Aldyl "A" pipe with a much higher resistance to SCG and with much greater resistance to rock impingement failure than standard Aldyl "A".

D. Alathon 5046-U

DuPont recognized the importance of the tie molecules, and the octene comonomer with the longer fish hooks that improved the efficiency of these tie molecules. In 1988 DuPont announced another improvement with the introduction of Alathon 5046-U. They added more octene comonomer to the resin, which decreased the density to 0.933 g/cc. The melt index remained at 1.1 g/10 min. This additional comonomer increased the number of "long fish hooks" and thus increased the efficiency of the tie molecules even more. This resulted in another order of magnitude improvement in slow crack growth resistance, as evidenced by 80ºC/120 psig stress rupture testing for Aldyl "A" pipe:

- LDIW - Alathon 5043 resin 10 hours
- Alathon 5043 resin 100 hours
- Alathon 5046-C resin 1000 hours
- Alathon 5046-U resin 10,000 hours

This product was also called improved Aldyl "A". An advantage of the lower density was increased flexibility for the pipe. This made the pipe easier to bend, easier to coil and uncoil – especially in cold weather, and easier to squeeze-off – especially in cold weather. These installation advantages, coupled with the improved SCG resistance, made Alathon 5056-U one of the best PE materials available for the natural gas distribution market.

E. Alathon 5046-O

The last change in the resin for Aldyl "A" pipe came in 1992 with the introduction of Alathon 5046-O. DuPont developed technology whereby the octene comonomer could be selectively placed on the high molecular weight molecules. Since the tie molecules are very high molecular weight, much of the octene comonomer was thus added to the molecules that directly affect long-term performance. Since the amount of comonomer remained the same, the density was still 0.933 g/cc and the melt index was still 1.1 g/10 min. This final change in the PE resin resulted in another improvement in slow crack growth resistance, as evidenced by 80ºC/120 psig stress rupture testing for Aldyl "A" pipe:

- LDIW - Alathon 5043 resin 10 hours
- Alathon 5043 resin 100 hours
- Alathon 5046-C resin 1000 hours
- Alathon 5046-U resin 10,000 hours
- Alathon 5046-O resin >30,000 hours

F. Summary of Resins

A summary of the various DuPont Alathon resins used to produce Aldyl "A" pipe is provided in Table 1 below:

Table 1 - DuPont Aldyl® "A" PE Pipe and Alathon® PE Resins

#	Name	Year	Density	Melt Index	Co-monomer	Color	Resin	Comment
1	Aldyl "A"	1966 – 1970	0.935	2.0	Butene	Tan	Alathon® 5040	Original Alathon resin
2	Aldyl "A"	1970 – 1984	0.939	1.2	Butene	Tan	Alathon 5043	Increased density due to quick burst test
	LDIW Aldyl "A"	1971 – 1972	0.939	1.2	Butene	Tan	Alathon 5043	Manufacturing issue
3	Improved Aldyl "A"	1984 – 1988	0.939	1.1	Octene	Tan	Alathon 5046-C	Changed comonomer
4	Improved Aldyl "A"	1988 – 1992	0.933	1.1	Octene	Tan	Alathon 5046-U	Added more comonomer
5	Improved Aldyl "A"	1992 -	0.933	1.1	Octene	Tan	Alathon 5046-O	Placed comonomer on high molecular weight molecules

IV. Rate Process Method Projections

Appendix A is a paper that I presented at the 2004 AGA Operations Conference, "Correlating Aldyl "A" and Century PE Pipe Rate Process Method Projections With Actual Field Performance". In this paper, I discuss the Rate Process Method (RPM) as a means of determining projected long-term performance based on laboratory elevated temperature stress rupture testing. An important feature of RPM is that it can be used not only for projections based on the primary load, internal pressure, but also for secondary loads, such as rock impingement. It is very important that the failure mode that is observed in the field rock impingement failures has been duplicated in the laboratory with an indentation jig. This is why RPM projections correlate so well with actual field experience.

Based on this field experience and the RPM projections in Appendix A, I believe that Avista has to be particularly concerned about any LDIW (low ductile inner wall) pipe in its system. I recommend that all LDIW pipe be replaced immediately regardless of the soil condition. If the Aldyl "A" pipe was manufactured prior to 1984, then the soil conditions need to be assessed.

Any Aldyl "A" pipe manufactured during or after 1984 has significantly more resistance to SCG and resistance to rock impingement failure. The same it true for the yellow PE 2406 materials or current unimodal PE 2708 materials. I would place all these materials in the same category as far as Avista assessment.

The new bimodal PE 2708 is in a new category by itself. This material has the highest SCG resistance of any gas pipe material in the world – with a published PENT (Pennsylvania Notch Test) value over 15,000 hours (actually over 30,000 hours on test), using the standard industry test conditions of 80ºC/2.4 MPa. This is significantly higher than the current 100-hour PENT requirement in ASTM D 2513 for all PE materials, and higher than the 500-hour PENT requirement for the new "high performance" PE materials. This bimodal PE 2708, as an MDPE material, has even higher SCG resistance than the new PE 100 RC materials, which have PENT values over 10,000 hours. The PE 100 RC materials have over five years experience in Europe with "sandless" backfill. The gas companies simply use the natural backfill – including rocks. With their very high SCG resistance, both bimodal PE 2708 and PE 100 RC materials are essentially immune to SCG failure from rock impingement.

Papers on PE 100 RC were presented at Plastics Pipe XV in Vancouver, BC during September 2010, and are available on request.

V. Recommended Protocol for Avista Assessment

Based on SCG resistance, RPM projections and their correlation with field experience, and my own experience with PE gas piping materials, here is my recommended protocol for Avista to assess their MDPE materials in their gas distribution system:

1) All Aldyl "A" pipe manufactured prior to 1984 should be evaluated for replacement.

> a) If the pipe is LDIW (low ductile inner wall) Aldyl "A" pipe, Avista should start a prioritized pipe replacement program immediately.
> b) If the Aldyl "A" pipe is installed in soil with rocks larger than ¾", Avista should start a prioritized pipe replacement program immediately.
> c) If the Aldyl "A" pipe is installed in sandy soil or in soil with rocks up to ¾" in size, the pipe should remain in service and normal leak surveys per DOT Part 192 should be followed.

2) All Aldyl "A" pipe manufactured during or after 1984 and all yellow MDPE pipe, both PE 2406 and unimodal PE 2708, should also be evaluated.

> a) If this pipe is installed in rocks larger than ¾" in size, Avista should evaluate the pipe and consider replacing it if they begin to experience rock impingement failures, and should conduct leak surveys more frequently than required by DOT Part 192, until replacement.
> b) If this pipe is installed in sandy soil or in soil with rocks up to ¾" in size, the pipe should remain in service and normal leak surveys should be followed.

3) All bimodal PE 2708 pipe may be installed by Avista in any soil condition. Due to the very high SCG resistance of this pipe it is essentially immune to rock impingement failure. This pipe is similar to bimodal PE 100 RC pipe that has been installed in Europe for the past five years in natural rocky backfill. This PE 100 RC material was developed in Europe so that gas companies could use "sandless" backfill, i.e. use the natural rocky backfill. The SCG resistance of bimodal PE 2708 is even greater than PE 100 RC.

Appendix A

Correlating Aldyl "A" and Century PE Pipe Rate Process Method Projections With Actual Field Performance

By Dr. Gene Palermo

A. Introduction

Dr. Chester Bragaw originally described the concept and mathematical basis for using the Rate Process Method for polyethylene (PE) pipe and fitting service projections (1) (2). The Plastics Pipe Institute (PPI) Hydrostatic Stress Board (HSB) conducted an extensive evaluation of this and other methods for forecasting the effective long-term performance of PE thermoplastic piping materials. Basically, all these methods require elevated temperature sustained pressure testing of pipe where the type of failure is of the slit or brittle-like mode. Dr. Gene Palermo and Ivan DeBlieu reviewed details of these evaluations and conclusions in their paper "*Rate Process Concepts Applied to Hydrostatically Rating Polyethylene*" (3).

As a result of these studies, HSB determined that the three-coefficient Rate Process Method (RPM) equation provided the best correlation between calculated long-term performance projections and known field performance of several PE piping materials. It also had the best probability for extrapolation of data based on the statistical "lack of fit" test. Dr. Gene Palermo provided further validation of the Rate Process Method by comparing RPM projections for PE pipe and fittings obtained at elevated temperatures with actual room temperature laboratory failures for the same pipe and fittings (4).

Many resin and pipe producers, as well as users, are using RPM to one degree or another to make relative judgments on specific materials and/or piping products. One example described in this paper has been using RPM to determine projected life of PE pipe exhumed from buried service. The gas engineer may use this projection to determine how much estimated life the PE pipe has, and whether he should leave pipe in the ground or dig it up. These projections are based on the primary load (which is the internal pressure) and service temperature. RPM can also be used to determine the effects of secondary loads such as indentation (rock impingement), squeeze-off, bending or deflection.

Another use of the Rate Process Method is projected performance of polyethylene fittings as discussed in "*Prediction of Service Life of Polyethylene Gas Piping Systems*" by Dr. Bragaw (5) and "*Designing PE Piping Systems: Old Questions and New Answers*" by Dean Hale (6). When testing and evaluating fittings, it is very important that all the failure modes be the same. Because fittings have different geometries, different failure modes may be observed at different test conditions. When applying the RPM calculation, all failure modes must be the same. The three RPM coefficients from each fitting will be different; again, this is due to their different geometries. The referenced paper by Dr. Bragaw shows different Arrhenius plot slopes (log t vs. 1/T) for the different fittings tested, indicating different coefficients due to the different activation energies for the fitting geometries. This RPM test protocol is not intended for mechanical fittings. An example of the Rate Process Method being used to solve a fitting problem is given in Section XII.

DuPont conducted several RPM experiments on butt-fused joints and also on butt fusion fittings. Generally, the butt fusion joint has a shorter failure time at the laboratory conditions selected for testing. Due to the shallower slope for the butt fusion failure mode compared to control pipe, many times the RPM projected performance for the butt fusion joint is actually longer than the RPM projected performance for the control pipe. This is probably why there are not many field failures for properly made butt fusion joints. DuPont also conducted several RPM experiments on socket fusion and saddle fusion joints.

After establishing the coefficients, an appropriate single-point elevated temperature stress rupture test may be established for quality control purposes, as discussed in "*Rate Process Method as a Practical Approach to a Quality Control Method for Polyethylene Pipe*" by Dr. Palermo (7).

B. RPM Test Procedure

Rate Process Method testing of pipe or fitting assemblies is conducted in accordance with ASTM D 1598, "*Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure*". Fittings are joined to pipe using standard heat fusion joining procedures, such as butt fusion, socket fusion, saddle fusion or electrofusion.

To do a typical RPM experiment requires a minimum of about 18 to 20 specimens at various temperature/pressure conditions. More specimens would provide greater certainty in making projections. Examples are shown in PPI Technical Note 16 (8).

Using slit failure mode data points, one calculates the A, B and C coefficients for the following three-coefficient Rate Process Method extrapolation equation:

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

Where:

t = slit mode failure time, hours
T = absolute temperature, °K
S = hoop stress, psi

Once the A, B and C coefficients are calculated, the RPM equation can be used for various performance projections (average failure time) at typical use temperature (average annual ground temperature) and use pressure conditions.

Mathematically, these RPM projections are sound. However, they are not absolute and are subject to various experimental errors, unknown deviations and judgment factors. Calculations from the RPM equation should be used in conjunction with all other mechanical, performance, and use factors in making judgments as to design, useful life or application suitability.

C. LDIW Aldyl "A" RPM Projections

Between 1970 and 1971, the DuPont Company produced some Aldyl "A" pipe that had a low ductile inner wall (LDIW) surface. Years later, in the early 1980's, some of their customers started experiencing failures in LDIW Aldyl "A" PE 2306 pipe that had been subjected to rock impingement. They were also experiencing some failures of LDIW Aldyl "A" pipe that had been squeezed-off. In an effort to explain the effect of this phenomenon on projected life performance, the DuPont Company agreed to conduct a major Rate Process Method research project on LDIW Aldyl "A" pipe exhumed from the area where the failures were occurring.

<u>1. Internal Pressure</u>
DuPont conducted RPM testing on the 2" IPS control (internal pressure only) LDIW Aldyl "A" pipe as received. The raw data for LDIW Aldyl "A" control pipe was summarized in Section IV. The selected temperatures were 80°C (176°F) and 60°C (140°F) with the internal pressures selected to assure that the failure mode was slow crack growth. To do the RPM calculation it is imperative that all the data have the same failure mode. In this case all the failures were an axial crack that initiated at the inside surface and propagated through the wall until failure occurred. The failures times were accelerated due to the degradation at the LDIW surface.

Based on underground thermocouple testing, the gas utility determined that the average annual service temperature was 21°C (70°F). The use pressure for the gas distribution system was 60 psig. The RPM projected performance for this lot of LDIW Aldyl "A" pipe at the use conditions of 60 psig and 70°F was an average failure time of about 150 years with a 5% lower confidence level (LCL) of 60 years. The RPM program calculates the LCL based on the scatter in the data. These data indicate there is a 95% probability that this lot of LDIW Aldyl "A" pipe would last 60 years at the conditions of 60 psig and an average annual ground temperature of 70°F, and a 50% probability it would last 150 years at the same conditions.

<u>2. Rock Impingement</u>
To simulate the rock impingement failures experienced by the gas utility, DuPont developed an indentation jig (Figure 1). It consists of a collar with a bolted thread of 28 UNS pitch. Seven turns of the bolt after it is flush with the pipe introduce an indentation of ¼". The bolted collar remains on the pipe the entire time it is subjected to stress

rupture testing to simulate the indentation from rock impingement in the field. Testing was again conducted at 80°C and 60°C with the internal pressure selected to assure failure at the indentation.

Due to the difference in slopes for the indentation failure mode vs. the control failure mode, if the pressure were too high, failure would occur in the pipe away from the indentation. At the lower pressures, all failures were inside to outside cracks that initiated at the indentation, just as was the case with the field failures. Also, when the indentation jig was removed, there was residual indentation, which looked identical to the failure mode observed by the gas utility in the field failures. Another characteristic feature of the indentation failures is that they were off axis by a few degrees (a failure due to just internal pressure is exactly in the axial direction). Rock indentation failures exhumed by the gas utility also had off-axis slit failures. These are the three characteristic features of a rock impingement field failure, and all three of these characteristic features were observed in the laboratory indentation failures. This indicates that DuPont successfully duplicated the rock impingement field failures with this laboratory indentation jig. At the gas utility use conditions of 70°F (21°C) and 60 psig the RPM projected performance for the indented LDIW Aldyl “A” pipe was an average failure time of 12 years with an LCL of 8 years.

This reduction of pipe life due to an LDIW surface was a significant discovery for the DuPont Company and as a result, they notified all Aldyl “A” customers to monitor this pipe with an increased leak survey frequency. This was a letter, known as the “Zerbe letter”, issued by Don Zerbe of DuPont to its customers on December 17, 1982, and is included in Attachment 1.

<u>3. Squeeze-Off</u>

To determine the RPM projected performance of squeezed LDIW Aldyl “A” pipe a similar experiment was conducted. All pipe samples were squeezed-off using DuPont recommended procedures and a single bar squeeze tool. The bar was brought to the gap stop and left there for one hour. The tool was removed and all specimens subjected to stress rupture testing at 80°C and 60°C. Again, due to the difference in slopes for the squeeze failure mode vs. the control failure mode, if the pressure were too high, failure would occur in the pipe away from the squeezed area. At the lower pressures, all failures were inside to outside cracks that initiated at the squeeze-off location. At the gas utility use conditions of 70°F and 60 psig the RPM projected performance for the squeezed LDIW Aldyl “A” pipe was an average failure time of 20 years with an LCL of 10 years.

A projected performance of Aldyl “A” pipe that was properly squeezed of less than 50 years was another significant discovery for the DuPont Company. As a result they notified their Aldyl “A” customers again and recommended reinforcement of squeezed LDIW Aldyl “A” pipe. This was a letter, known as the “Roddy letter”, issued by Ed Roddy of DuPont to its customers on August 25, 1986, and is included in Attachment 2.

4. Deflection

Excessive earth loading can cause polyethylene pipe to deflect, which is another form of secondary loading. To simulate field deflection from earth loading, DuPont developed a “deflection jig” as shown in Figure 2. With this jig, varying levels of deflection may be achieved, where deflection is defined as the change in OD (ΔY) divided by the OD. For 5% deflection, $\Delta Y/D$ is 0.05. For an RPM experiment, all deflection levels must be the same and all failure modes must be the same. The typical deflection failure mode is an axial slit on the larger radius surface of the oval shaped pipe. DuPont conducted the RPM deflection experiment with 5% deflection on all specimens. At the use conditions of 70°F and 60 psig the RPM projected performance for the 5% deflected LDIW Aldyl “A” pipe was an average failure time of 18 years with an LCL of 9 years.

5. Bending

The gas utility also experienced a few failures of Aldyl “A” pipe from excessive bending. In this case the field failure mode is a circumferential crack that initiates at the outside surface. To simulate this secondary load of bending, DuPont developed a bending jig (Figure 3). The % bending strain calculation is shown in Figure 4. Again all calculations must be made using the same bending strain and the same failure mode. Due to the different slopes for the control pipe failure mode and the bending failure mode, if the pressure is too high, the failure mode is an axial slit in the pipe away from the bend area. At lower internal pressures, the failure mode is a circumferential slit in the bend area, the same failure mode observed in the field failures. DuPont conducted the RPM bending experiment with 6% bend strain on all specimens. At the gas utility use conditions of 70°F and 60 psig the RPM projected performance for the 6% bend strain LDIW Aldyl “A” pipe was an average failure time of 5 years with an LCL of 3 years.

Figure 5 is a composite plot for LDIW Aldyl “A” pipe summarizing RPM projected slit slopes at the gas utility average temperature of 70°F for control pipe (internal pressure only) and various secondary loads. This composite plot demonstrates the change in slopes for the different failure modes.

D. Gas Utility A Field Experience with LDIW Aldyl “A” Pipe

1. Rock Impingement

Gas utility A first started to experience rock impingement failures in LDIW Aldyl “A” pipe after five years of in-ground service. The number of rock impingement failures increased every year and peaked after 12 years of installation. The number of failures then began to decrease every year. This field experience exactly correlates with the RPM projected performance of indented LDIW Aldyl “A” pipe at their use conditions (average failure time of 12 years with a 5% LCL of 8 years).

2. Squeeze-Off

The first failure in Aldyl “A” pipe experienced by this gas utility due to a squeeze-off was after 12 years of installation. The number of squeeze-off failures has increased slightly. This field experience is consistent with the RPM projections for squeeze-off failures at the use conditions calculated (average failure time of 20 years with a 5% LCL of 10 years).

3. Deflection

The gas utility did not experience any failures in LDIW Aldyl “A” pipe due to excessive deflection. The RPM projection for 5% deflected LDIW Aldyl “A” pipe at the calculated conditions results in an average failure time of 18 years with an LCL of 9 years. Based on this projection, DuPont had developed installation guidelines to prevent failures due to this excessive deflection.

4. Bending

Some bending failures were experienced after just a few years of installation, which exhibited a circumferential slit. The RPM projection for LDIW Aldyl “A” pipe bent to a 6% bend strain at the gas utility calculated conditions is an average failure time of 5 years with an LCL of 3 years. Based on this projection, the gas utility installed some LDIW pipe at a bend strain of about 6%, which corresponds to a bend radius of about 10 times the pipe OD. This exceed DuPont’s minimum bend radius recommendation of 20 times the OD for Aldyl “A” pipe, but provided valuable feedback for the gas utility to reinforce requirements for installation.

E. Gas Utility B Field Experience with LDIW Aldyl “A” Pipe

Another gas utility also kept very good records of Aldyl “A” PE 2306 pipe and fitting failures. They separated failures into two groups based on year of production. One group was Aldyl “A” pipe produced between 1971 and 1973, which would include LDIW pipe. Recall that not all the pipe produced by DuPont in those years had an LDIW surface. The other group was Aldyl “A” pipe produced between 1974 and 1984. This was all “standard” Aldyl “A” pipe. After 1984, DuPont produced “”improved’” Aldyl “A” pipe. The table below summarizes all their Aldyl “A” failures for the two groups based on failure mode. The units are number of failures per one million feet of pipe per year:

Failure Mode	Aldyl “A” (1971 – 1973)	Aldyl “A” (1974 – 1984)
Rock impingement	1.26	0.17
Saddle fusion	1.25	0.51
Fitting crack	0.75	0.30
Fitting bend	0.68	0.32
Squeeze-off	0.61	0.32
Socket fusion	0.57	0.49
Pipe crack	0.27	0.11
Pipe bend	0.11	0.06
Other	2.04	0.75
Total	7.54 failures/ MM ft pipe	3.03 failures/ MM ft pipe
	0.040 leaks/mile	0.016 leaks/mile

Several very interesting observations can be made about the failure summary in this table. 1) First of all, the leak rate for every failure mode decreased for the 1974-1984 Aldyl “A” compared to 1971-1973 Aldyl “A”. This of course is due to the fact that a portion of the 1971-1973 Aldyl “A” pipe contains an LDIW surface. 2) Next, the overall failure rate for 1971-1973 Aldyl “A” of 0.040 leaks per mile is about an order of magnitude LESS than the leak rate for metal pipe of 0.43 leaks per mile as reported by AGA (9).

3) The failure mode with the highest failure rate is rock impingement, which is consistent with the first gas utility’s field experience. The next highest failure rate is for fittings, which include saddle fittings and socket fittings. This is to be expected since heat fused fittings have notches that act as crack initiators. The next category is squeeze-off and the lowest failure rate is for pipe, which is again to be expected.

F. Aldyl “A” and Improved Aldyl “A” RPM Projections

During the 1980’s the DuPont Company had a major research project to conduct RPM testing on many Aldyl “A” and Improved Aldyl “A” pipe and fitting components. These RPM data can be used to project Aldyl “A” performance at this gas utility’s service conditions of an average annual ground temperature of 73°F (23°C) and an operating pressure of 40 psig. These RPM projections are then compared to actual field experience.

1. Pipe

Figure 6 is a composite plot for control pipe (internal pressure only) comparing LDIW Aldyl “A”, standard Aldyl “A” and improved Aldyl “A” at the average annual temperature of 73°F. The table below compares the RPM projected performance for these three generations of control Aldyl “A” pipe at 73°F and 40 psig with the gas utility’s actual field experience.

Control Aldyl “A” Pipe	RPM Projection at 73°F/40 psig (Years)	Field Experience (Failures/MM ft/year)
LDIW	267	0.27
Standard	3408	0.11
Improved	9693	0.0

The RPM projected performance is consistent with this gas utility’s field experience for pipe. As the RPM projected lifetime at their use conditions increases, the number of field failures experienced decreases.

2. Indented Pipe
Figure 7 is a composite plot for indented pipe (indentation jig with ¼" indentation) comparing LDIW Aldyl "A", standard Aldyl "A" and improved Aldyl "A" at the gas utility's average annual temperature of 73°F. For improved Aldyl "A" all failures occurred away from the indentation jig. All failure modes were axial slits in the pipe. The table below compares the RPM projected performance for these three generations of indented Aldyl "A" pipe at 73°F and 40 psig with this gas utility's field experience.

Indented Aldyl "A" Pipe	RPM Projection at 73°F/40 psig (Years)	Field Experience (Failures/MM ft/year)
LDIW	23	1.26
Standard	88	0.17
Improved	9693	0.0

Again, the RPM projected lifetime at this gas utility's use conditions correlates well with actual field experience for rock impingement failures.

3. Squeezed Pipe
Figure 8 is a composite plot for squeezed pipe (standard squeeze-off procedures) comparing LDIW Aldyl "A", standard Aldyl "A" and improved Aldyl "A" at the gas utility average annual temperature of 73°F. For improved Aldyl "A" all failures occurred away from the squeeze-off location. All failure modes were axial slits in the pipe. The table below compares the RPM projected performance for these three generations of squeezed Aldyl "A" pipe at 73°F and 40 psig with the gas utility field experience.

Squeezed Aldyl "A" Pipe	RPM Projection at 73°F/40 psig (Years)	Field Experience (Failures/MM ft/year)
LDIW	46	0.61
Standard	420	0.32
Improved	9693	0.0

Once again, the RPM projected lifetime at this gas utility's use conditions correlates well with actual field experience for squeeze-off failures.

G. Gas Utility C Field Experience with Century Pipe

Gas utility C installed Century PE 2306 pipe in their gas distribution system in the mid 1970's. Century pipe was a tan colored pipe, marketed primarily in the Midwest, made to look like tan Aldyl "A" pipe. In the late 1980's, the gas utility noted that in one area of their system they were experiencing several rock impingement failures in Century pipe after only a few years of service. In another area, they were not experiencing any failures with Century pipe. Nevertheless, the state Public Service Commission notified the gas company that they had to remove ALL Century pipe from their gas distribution system.

The gas utility planned to remove Century pipe (bad) from the area where they were experiencing failures, but they felt they did not need to remove Century pipe (good) from the area where they were not experiencing any failures. They noted that the Century pipe in the two areas had been installed at different times and also the Century pipe had two different production lots. The gas utility contacted DuPont to see if they could conduct RPM testing on the two lots of Century pipe, and then use the results to justify to their Public Service Commission leaving the "good" Century pipe in the ground. They exhumed several feet of "good" and "bad" Century pipe and sent it to DuPont for RPM testing.

H. Century Pipe RPM Testing

The DuPont Company conducted Rate Process Method testing on the exhumed Century PE 2306 pipe in a similar fashion, as was done for Aldyl "A" pipe. Both the "good" and "bad" lots of Century pipe were tested at conditions that result in slit failures.

<u>1. Control Pipe</u>
Control pipe samples (primary internal pressure only) were tested at selected temperatures and internal pressures to produce axial slit failures. At the gas utility conditions of an average annual ground temperature of 60°F (15°C) and an average internal pressure of 60 psig, the RPM projected mean failure time for both lots of Century pipe was over 10,000 years and the 5% LCL was over 1000 years. These RPM projections would indicate good performance for the control (internal pressure only) Century pipe. The gas utility did not have any failures in control pipe for either pipe lot, which correlates well with the RPM projection.

<u>2. Squeezed Pipe</u>
Squeezed pipe RPM projections are based on testing the same lot of 2" Century pipe that has been squeezed-off using standard squeeze-off procedures. DuPont used a single bar squeeze tool with a gap stop of 0.340", which is the standard for Aldyl "A" pipe. After reaching the gap stop, each pipe specimen was left in the squeeze tool for one hour. Specimens tested at too high an internal pressure resulted in an axial slit failure away from the squeeze location. At lower pressures, all failures occurred at the squeeze location for the "bad" pipe lot with a slit initiating at the inside surface. At the gas utility conditions of an average annual ground temperature of 60°F and an average

internal pressure of 60 psig, the RPM projected mean failure time for the "bad" lot of squeezed Century pipe was 300 years and the 5% LCL was 20 years. The "good" pipe lot failed away from the squeeze location at all test conditions. Although the gas utility did not experience any squeeze-off failures, the Rate Process Method does show a distinct difference in the slit or long-term performance of these two pipe lots.

3. Indented Pipe

Indentation is the laboratory method developed by DuPont of simulating point loading such a rock impingement. Indentation jigs were place on both the "good" and "bad" Century pipe lots and tightened to introduce ¼" of indentation. This indentation jig remains on the pipe for the duration of the test.

Again, at higher internal pressures, failure occurred in the pipe away from the indentation jig. This is due to the different slope for the indentation failure mode. At the gas utility conditions of an average annual ground temperature of 60°F and an average internal pressure of 60 psig, the RPM projected mean failure time for the "bad" lot of indented Century pipe was 30 years and the 5% LCL was 8 years. The "good" pipe lot failed away from the indent location at all test conditions. This RPM projection for indented pipe correlates very well with this gas utility's field experience. They experience several indent failures after a few years for the "bad" pipe and no indent failures for the "good" pipe.

Based on these RPM projections developed by the DuPont Company, in 1990 gas utility C requested the state Public Service Commission to allow them to leave the "good" Century pipe in service. The PSC granted their request because the RPM projections for Century pipe correlated so well with their field experience of no field failures to date. To date, after 20 more years of service, that "good" Century pipe is still in their distribution system and they still have not experienced **any** slit failures – just as predicted by the Rate Process Method.

I. Conclusion

The Rate Process Method is a very powerful tool that can be used to determine the projected life of old generation polyethylene pipe that is in service for natural gas distribution. RPM can project not only the life of control pipe based on internal pressure, but also the life of the pipe subjected to secondary loads such as rock impingement, squeeze-off, bending and deflection. RPM can also project the life of heat fusion fittings, such as butt fusion, socket fusion, saddle fusion and electrofusion. In addition, based on scatter of the data, RPM can project the mean or average failure time at use conditions and the lower confidence level at use conditions.

RPM can be used for older generation PE materials like Aldyl "A", Century, PE 2306, PE 3306, PE 3406 and PE 3408 materials. Because the new PE materials have such improved resistance to slow crack growth, RPM is not practical for modern PE 2708, PE 4710 or PE 100 materials because the slit failures simply take too long to generate in laboratory conditions.

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8. Plastics Pipe Institute Technical Note 16, “Rate Process Method for Projecting Performance of Polyethylene Piping Components”.
9. P. D. Schrickel, “Plastic Pipe Performance”, AGA Operating Section Proceedings – 1984.

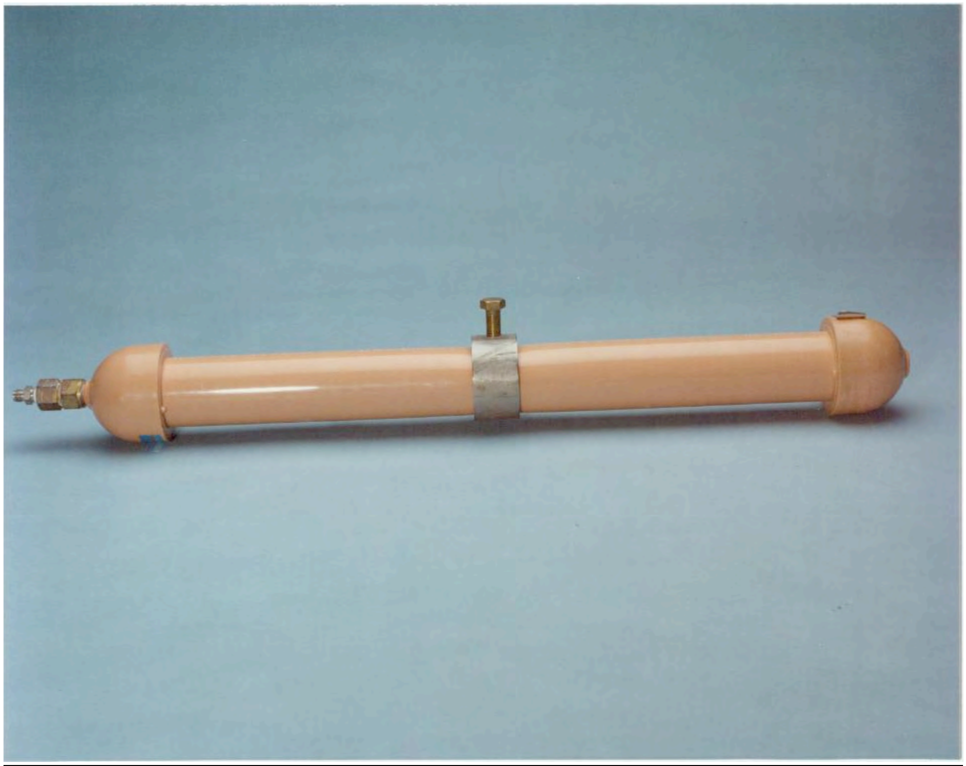

Figure 1 – Indentation Jig

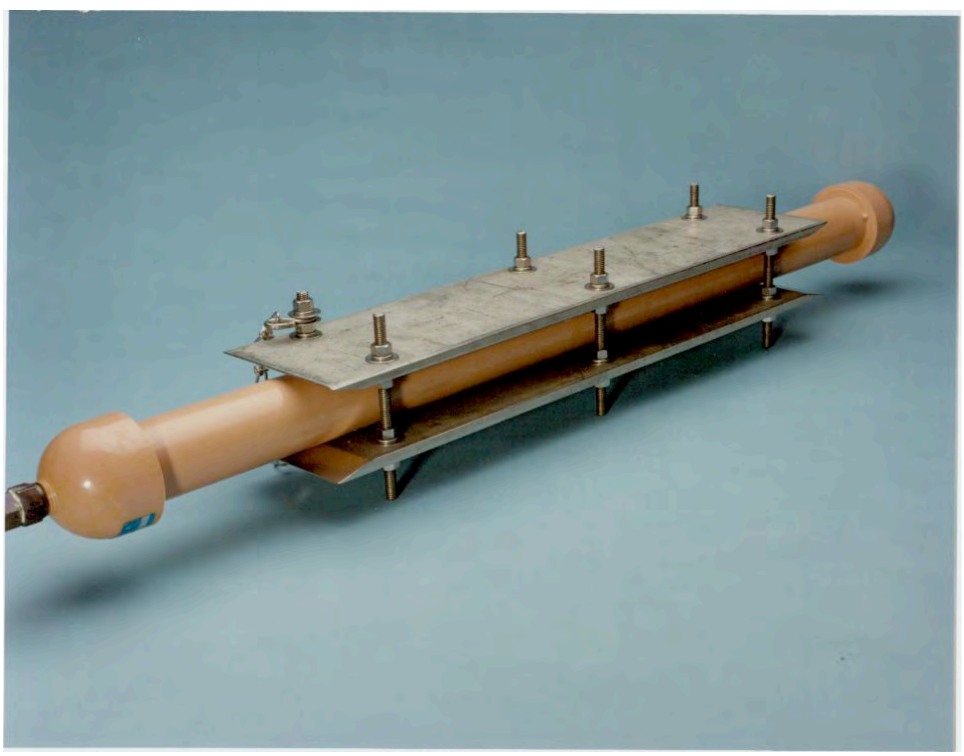

Figure 2 – Deflection Jig

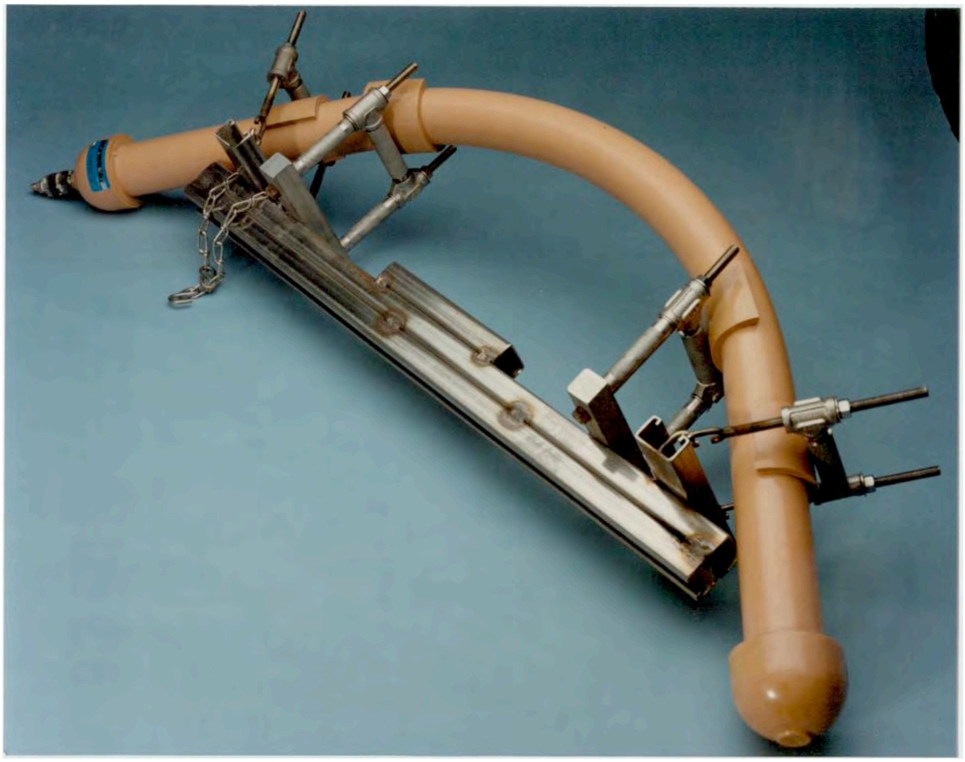

Figure 3 – Bending Jig

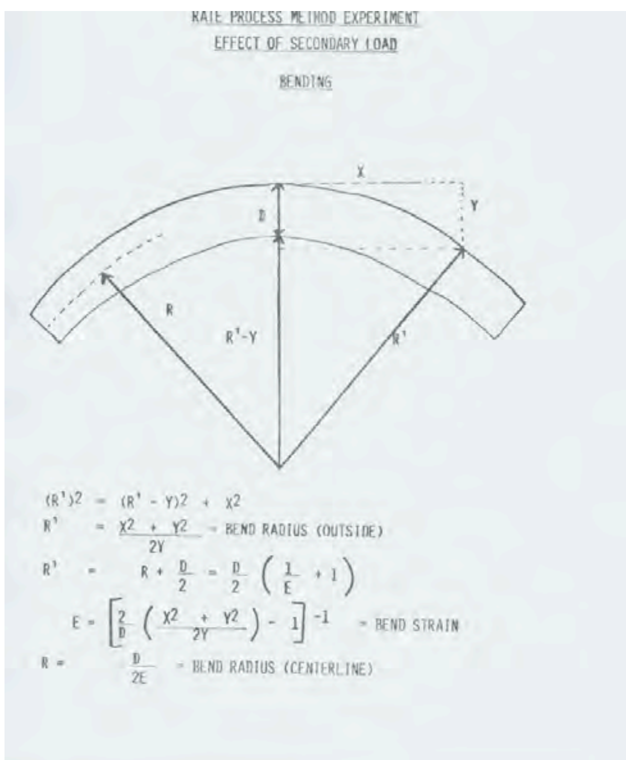

Figure 4 – Percent Bend

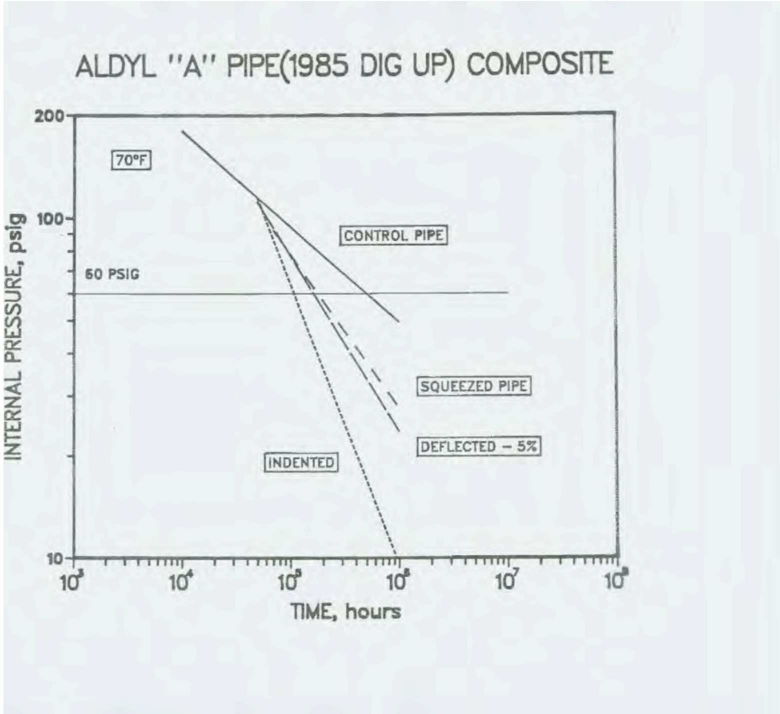

Figure 5 – Composite Showing Control Pipe and Secondary Loading Effects

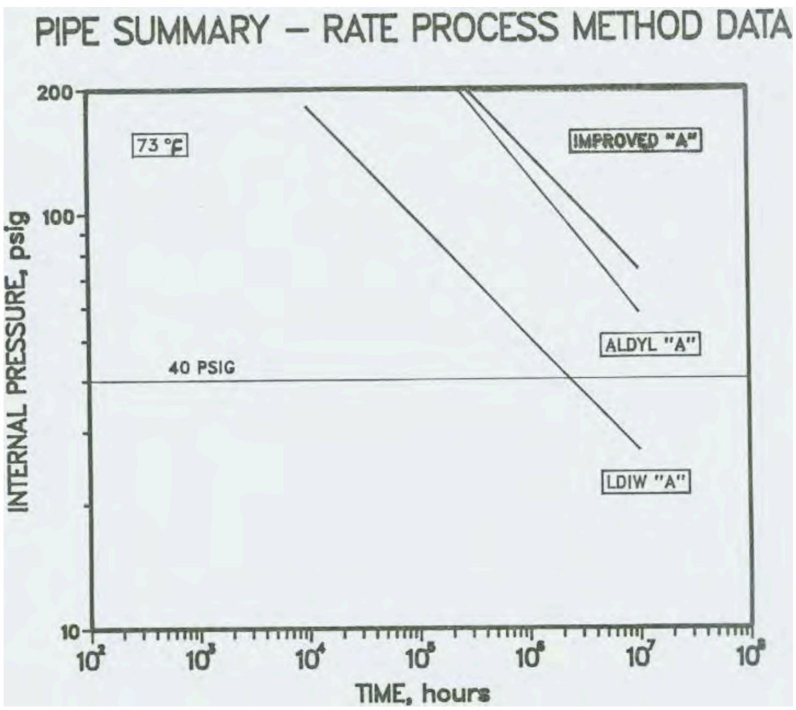

Figure 6 – Composite of Three Generations Control Aldyl “A” Pipe

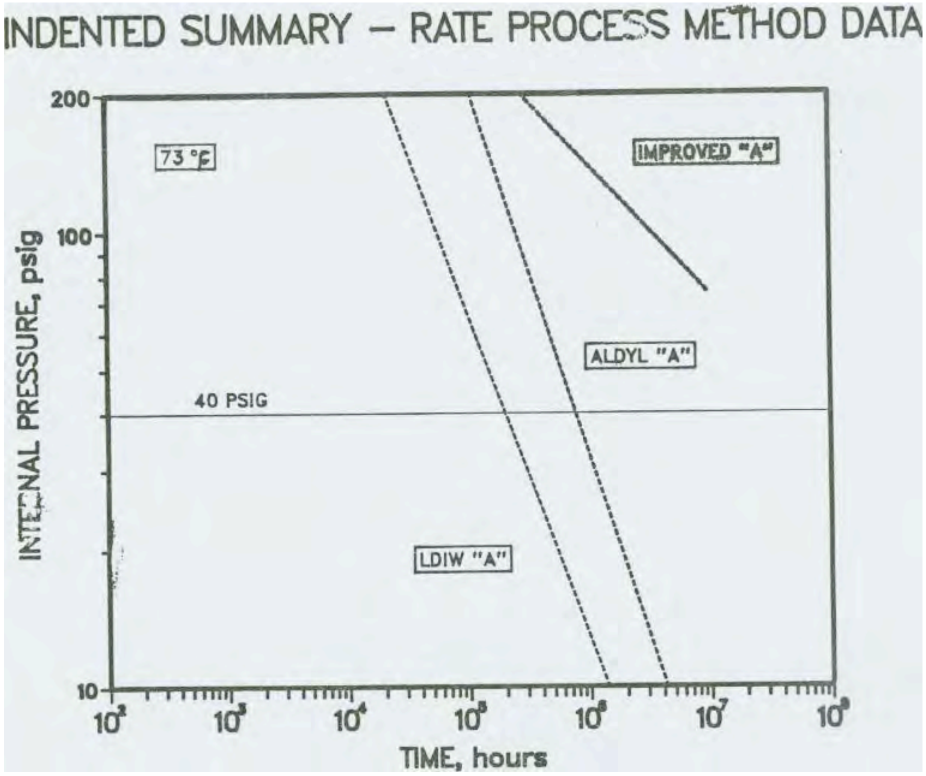

Figure 7 - Composite of Three Generations Indented Aldyl "A" Pipe

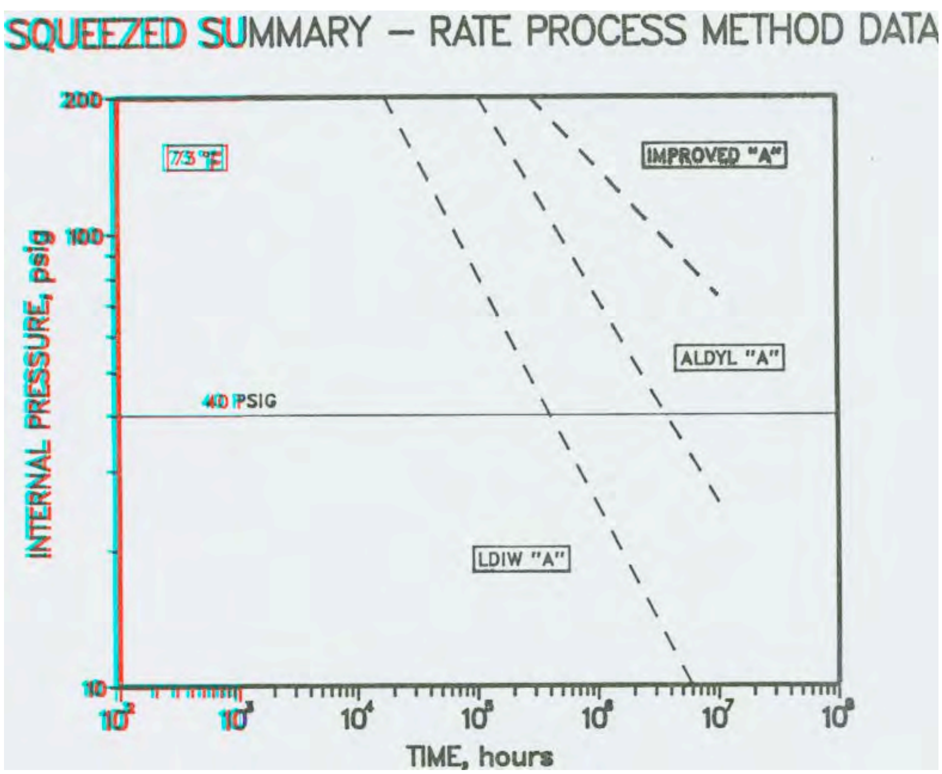

Figure 8 - Composite of Three Generations Squeezed Aldyl "A" Pipe

Attachment 1 – DuPont "Zerbe Letter"

11/04/2003 17:18 FAX 9184469369 UPONOR ALDYL CO 005

Z-189 REV. 4/81

DU PONT
ESTABLISHED 1802

E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED
WILMINGTON, DELAWARE 19898

POLYMER PRODUCTS DEPARTMENT

December 17, 1982

It has now been over 18 years since Du Pont developed and introduced the first complete polyethylene piping system designed specifically to meet the needs of the gas distribution industry. Over this period of time, the use of Du Pont's Aldyl® "A" piping system and other polyethylene systems has increased to the point that 84% of the gas distribution pipe installed in 1981 was polyethylene. The outstanding overall performance of the polyethylene pipe installed since 1964 is the primary reason that polyethylene pipe has become the standard for the industry. We believe that the value of polyethylene piping systems has been well documented.

As a responsible long-term supplier committed to the gas industry, we have had a continuing research program aimed at defining the ultimate service life and failure modes of polyethylene pipe in gas distribution service. This program has been and is being supplemented by information received from gas utilities on their experience with Aldyl® "A" pipe.

In metal pipe, corrosion has been the ultimate failure mechanism that has determined when pipe should be replaced. So far, nearly all failures reported in polyethylene piping systems have been caused by either third-party damage or improper fusion practices during installation. These problems can and generally have been minimized by more extensive education and training programs. Although these causes may continue to be the primary reasons for leaks, we believe that every utility with polyethylene piping systems should maintain well-defined leak analysis procedures. Documentation and analysis of individual leak occurrences should help to define the ultimate failure mechanisms, the expected useful life, and appropriate repair or replacement programs.

As in the past, we will continue to assist our customers in planning details of their leak analysis programs including record-keeping, test methods, etc. As an example of the new information such programs can provide, two of our customers have reported instances* of leaks due to slits in Aldyl® "A" pipe made before 1973. The slits have only occurred in 1-1/4" and larger sized pipe. Nearly all of the slits were in pipe installed in point contact with rocks. This low frequency of leaks due to slits has not been reported for pipe made after 1972. Our records indicate that a process improvement was made in late 1971 and early 1972 as part of our continuing effort to utilize our most up-to-date technology. We believe, therefore, that Aldyl® "A" pipe made since that time is more resistant to the formation of slits from point contact with rocks. However, as with coated steel pipe, polyethylene pipe should be installed using established methods which avoid point loading with rocks.

After finding these leaks, the two utilities have increased the frequency of their leak detection surveys for pipe installed before 1973, particularly in those subdivisions where other leaks suggest that rocks may have been included as part of the backfill. We believe that all utilities with Aldyl® "A" pipe installed prior to 1973 should consider more frequent leak detection surveys. The attached sheet shows the purchases by year for your company prior to 1973.

In the future, as we learn of other significant field performance data on our product or develop our own laboratory data, we will share this information with you. High quality polyethylene systems have become an important part of the gas distribution business in providing good performance and safety at minimum costs for installation and repair. It is important as the amount of pipe grows and service times increase, that the management of system maintenance proceeds on a rational, planned basis. We hope the ideas and information included here are helpful toward that end. We look forward to your comments and questions.

Sincerely,

Don F. Zerbe, Jr.
Marketing Manager
Aldyl® Piping Systems

DFZ:dmst
Attachment

* Averaging less than 1% of all field repairs.

Attachment 2 – DuPont "Roddy Letter"

11/04/2003 17:16 FAX 9184469369 UPONOR ALDYL CO 002

DU PONT ALDYL® PIPING SYSTEMS
QUALITY • INNOVATION • SERVICE

E. I. DU PONT DE NEMOURS & COMPANY (INC.) WILMINGTON, DELAWARE 19898
ALDYL® Piping Systems

August 25, 1986

Dear Customer:

Over twenty years have passed since the first full Aldyl® "A" Polyethylene Piping System was installed in gas distribution service. During those decades both the gas industry and system suppliers have gained experience. As a result, today's systems incorporate improved resins and protective additives, system components are readily available, tooling and installation techniques have been improved, and testing methods have been developed to define design strength and estimate long-term system performance.

Consistent with our position as a reliable and responsible supplier to the gas distribution industry, Du Pont has continued to conduct research programs aimed at new product development and better understanding of existing product performance. We have, over the past years, shared the results of this research effort with you, our customers.

One of the major technical advancements derived from these research programs has been the development by Du Pont of the Rate Process Method (RPM) to estimate long-term system performance. This accelerated test for estimating pressure capability at use conditions is based on the demonstrated Arrhenius principle, relating material strength to temperature. The method is supported by many hundreds of data points at several test temperatures.

RPM estimates enable us to quantify performance of Aldyl® "A" systems. These estimates have shown certain limitations in some 1-1/4 inch and larger Aldyl® pipe installed prior to 1973 which were not previously shown by standard state-of-the-art testing (ASTM D-2837) available at the time. RPM estimates have confirmed that service life of this pipe may be reduced by rock impingement, which is contrary to recommended practice, as communicated previously.

It has now also been shown that the life of pre-1973 1-1/4 inch and larger pipe is shortened at squeeze-off points. For example, RPM estimates show that for squeezed pre-1973 SDR-11 pipe operating at 60 psig and a ground temperature of 70°F (e.g. conditions in parts of the southwestern U.S.) a mean

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DU PONT

life of about 20 years, after squeeze, can be expected. When ground temperature is 60°F, however, the mean life of a squeeze point in such pipe is projected to be about 50 years. The effects of temperature, rock impingement and squeeze-off predicted by RPM are being substantiated by actual field experience.

Based on this new information, reinforcement is recommended to extend the life of pre-1973 pipe when squeeze-off procedures are used. Alternatively, through your own field experience you may have developed other methods you have found to be effective to extend life of squeezed polyethylene pipe.

There are a number of suppliers of reinforcement clamps, and an ASTM guide for selection and use of full encirclement type clamps is near completion. Key items of this proposed guide are summarized in the attachment.

RPM estimates show that for Du Pont's current Aldyl® "A" product:

- Resistance to failure as a result of rock impingement has been improved significantly; and
- Long-term performance is unaffected by squeeze-off (provided proper procedures are followed).

We trust this update on laboratory results and field experience will be helpful in managing Aldyl® systems. Our RPM data on squeeze-off, rock impingement, deflection and other conditions are available, should you wish to use them to help characterize your system, and we welcome discussion of these data with you. We look on such exchanges of information as part of our ongoing partnership in the safe, economical distribution of natural gas.

Sincerely,

E. J. Roddy
Manager
Aldyl® Piping Systems, U.S.
SPECIALTY PRODUCTS & SERVICES DIVISION

EJR1:04/dle
8/25/86
Attachment

SUMMARY OF PROPOSED ASTM DOCUMENT

STANDARD GUIDE FOR THE SELECTION AND USE OF FULL ENCIRCLEMENT TYPE BAND CLAMPS FOR REINFORCEMENT OR REPAIR OF POLYETHYLENE GAS PRESSURE PIPE

- Full encirclement band clamps can be used to reinforce PE pipe where it has been squeezed-off.
- The user should confirm that the band clamp manufacturer recommends his product for reinforcement of PE pipe.
- The user should obtain recommended step-by-step installation instructions from the band clamp manufacturer.
- General considerations to determine appropriateness of using band clamps, design requirements for band clamps, and test methods for evaluation are the responsibility of the band clamp manufacturer.
- The band clamp should be long enough so that it extends 2.5 inches beyond each side of the squeeze-off area.
- The PE pipe should be clean and rounded prior to band clamp installation.

This proposed ASTM document is on the current F-17 Main Committee ballot. Several wording changes may occur as the document proceeds through the ASTM ballot process. Since the proposed balloted document cannot be reproduced or quoted, the key items related to reinforcement of squeezed PE pipe have been summarized here. The final approved document may appear in the <u>1987 Book of ASTM Standards</u>.

EJR1:04/dle
8/25/86

Appendix B
Dr. Gene Palermo CV

Palermo Plastics Pipe (P^3) Consulting

Dr. Gene Palermo
654 Watershaw Drive
Friendsville, TN 37737

PH: 865-995-1156
FAX: 865-995-0115
website: **www.plasticspipe.com**
e-mail: **gpalermo@plasticspipe.com**

I. Consultant Services Offered

A. Manufacturers

Palermo Plastics Pipe (P^3) Consulting will aid plastic pipe manufacturers (resin companies and pipe companies) to achieve HDB (Hydrostatic Design Basis) and MRS (Minimum Required Strength) pressure ratings through the Hydrostatic Stress Board (HSB), assist with HSB special cases, develop or revise industry standards (ASTM, CSA, AASHTO, ISO), write petitions to the DOT, and/or aid in marketing plastic pipe products to the end user.

B. End users

Palermo Plastics Pipe (P^3) Consulting will aid end users, primarily gas utilities, to evaluate or qualify plastic pipe products (primarily polyethylene and polyamide 11), revise industry standards, and/or conduct failure analysis of plastic pipe products. P^3 Consulting will also present technical seminars at gas company locations to provide background on polyethylene pipe, polyamide 11 pipe or new plastic piping materials for the gas industry.

C. Laboratories
Palermo Plastics Pipe (P^3) Consulting will work with laboratories or research organizations to keep abreast of domestic and international standard test methods and standard specifications, and/or write proposals for and then guide research projects for plastic pipe.

D. Litigation Cases
Palermo Plastics Pipe (P^3) Consulting is available for litigation cases involving plastic pipe products, particularly plastic pipe used for natural gas distribution.

II. Dr Gene Palermo

Dr. Gene Palermo received a Bachelor of Science in Chemistry from St. Thomas College in St. Paul, MN in 1969 and a Ph.D. in Analytical Chemistry from Michigan State University in 1973.
Dr. Palermo has been in the plastic piping industry for over 30 years. He worked for the Dupont Company from 1976 to 1995 in the Aldyl "A" polyethylene (PE) pipe business for natural gas distribution. Dr. Palermo developed the initial use of polyamide (PA) 11 for high-pressure gas distribution, up to 300 psig, to replace metal pipe while with Elf AtoChem during 1995 and 1996.

Dr. Palermo was the Technical Director for the Plastics Pipe Institute (PPI) from 1996 until 2003. As Technical Director, Dr. Palermo was chairman of the Hydrostatic Stress Board (HSB) on which he has served for 20 years to develop pressure rating methods for plastic pipe; and chairman of the Technical Advisory Group for ISO/TC 138 for international plastic piping systems. Dr. Palermo has developed standards for plastic pipe and fittings in several standards bodies; ASTM F17, CSA, AASHTO, and ISO/TC 138.

Most of Dr. Palermo's expertise has been in the natural gas distribution industry. He has been a member of the AGA Plastic Materials Committee for 20 years, the Gas Pipe Technology Committee for seven years, an instructor for the DOT inspector training school for 15 years, and a member of the Plastic Pipe Database Committee since its inception four years ago. Dr. Palermo also developed PPI's one day Technical Seminar for the gas distribution industry.

Dr. Palermo currently serves as a member of PPI, AGA, GPTC, ASTM F 17 and D 20, CSA, TRB and ISO/TC 138.

III. Awards Received

Dr. Gene Palermo just received the **AGA (American Gas Association) Platinum Award of Merit** from the American Gas Association. This is the highest award given by AGA to its members. Dr. Gene Palermo had previously received the AGA Award of Merit in 1995 in recognition of several presentations made at plastic gas pipe industry meetings, and also serving as moderator at AGA Operations Conferences and Plastic Pipe Symposiums. Dr. Palermo also received the AGA Silver Award of Merit in 2002 for having faithfully and constructively served the American gas industry, and for making continuous and extensive contributions to further the interests and promote the welfare of the gas industry and of the public.

Within ASTM F 17, Dr. Palermo has received two Awards of Appreciation in recognition of his many years of outstanding service and active participation in the plastic piping standards work of ASTM F 17, and a Special Service Award for his many technical contributions and development of plastic piping standards. Dr. Palermo received the Paul Finn Memorial Award in 1995 for his distinguished and continuous service to ASTM F 17 (plastic pipe standards), and particularly for steadfast contributions to the development of sound engineering standards, particularly for plastic gas pipe standards. Dr. Palermo received the Rinehart Kuhlmann Award in 2002 in acknowledgment of faithful and significant contributions in furthering the cause of sound and effective plastics piping standardization. Most recently, in 2005 Dr. Palermo received the ASTM **Award of Merit**, which is the highest award given within ASTM.

Dr. Palermo was also recognized by the US Department of Transportation (Transportation Safety Institute) for outstanding performance as an associate staff in the Pipeline Safety Division in teaching DOT inspectors about plastic gas pipe standards in ASTM and ISO, plastic pipe pressure ratings methods from ASTM and ISO, plastic pipe failure analysis and new plastic pipe materials for the natural gas industry.

IV. Gas Pipe Industry Experience

For over 30 years Dr. Gene Palermo has been primarily involved in plastic piping systems for the natural gas distribution industry. Most of those years were with the Dupont Company where he worked with Aldyl “A” polyethylene gas pipe. He presented several industry papers on the use of the Rate Process Method (RPM) to forecast the life expectancy of polyethylene gas pipe and fittings. At Plastics Pipe XII in Milan (April 2004) Dr. Palermo presented a paper correlating RPM projections with actual field performance for polyethylene gas pipe materials. While with DuPont, Dr. Palermo also conducted several failure analyses of Aldyl “A” polyethylene pipe components and wrote several failure analysis reports for gas companies.

Dr. Palermo was hired by Elf AtoChem in 1995 to develop an all plastic piping system made from polyamide (PA) 11 to be used for high-pressure gas distribution systems as a replacement for metal pipe. He wrote several ASTM and CSA standards for the polyamide 11 piping system. He worked with PPI member companies to develop polyamide 11 pipe, butt fusion fittings, mechanical fittings, meter risers, transition fittings, and valves and also developed a butt fusion procedure for joining polyamide 11 pipe and fittings using the same butt fusion equipment that gas companies use for polyethylene pipe and fittings.

He has been actively involved in the AGA Plastic Materials Committee (PMC) since 1981. He presented several papers at various AGA PMC Winter Workshops. He has provided PMC members with liaison reports for PPI and ISO activities and served as the chairman of the Code, Standards and Regulatory task group for AGA PMC. Dr. Palermo has also been an active member of the AGA Gas Pipe Technology Committee (GPTC) since 1995. He has chaired several projects in the Plastics task group and the Design task group. He is currently a voting member on the Main Body Committee of GPTC.

Dr. Palermo served on the Plastic Pipe Database Committee, which is a joint government/industry committee to develop a database of plastic pipe and fitting failures that occurred in the gas industry. This database will confirm that industry standards for plastic pipe systems used in the gas industry result in outstanding performance for the end user.

More recently, Dr. Palermo has developed a one-day technical seminar for plastic pipe materials used in the gas industry. This seminar is intended to provide a background on plastic pipe materials, primarily polyethylene, to update gas engineers on recent developments in ASTM and ISO standards for the gas industry, and to provide information on new plastic pipe materials for the gas industry. These include polyamide 11 for high pressure gas applications to replace metal pipe, crosslinked polyethylene for niche applications that require increased slow crack growth resistance, PE 100 materials that are considered the next new generation of polyethylene materials and multiplayer pipe for higher pressure gas applications.

V. Plastic Pipe Standards Activities

A. ASTM

1. Dr. Gene Palermo has been a member of ASTM F 17 since 1982, and D 20 since 1999. He has been primarily involved in the following F 17 plastic pipe standards subcommittees:

F17.10 Fittings
F17.20 Joining
F17.26 Olefins
F17.38 ISO
F17.40 Test Methods
F17.60 Gas

F17.61 Water
F17.90 Executive
F17.94 Terminology

Dr. Palermo has served as chairman of F17.94 on Terminology and F17.38 on ISO. He is also a member of the F17.90 Executive Committee for F17. Dr. Palermo is currently the Chairman of ASTM F17 Division I.

2. New plastic piping standards that Dr. Palermo developed or existing plastic piping standards that Dr. Palermo revised include:

- Added 80°C sustained pressure requirements to water pipe standards to assure slow crack growth resistance.
- Revised D 2513 quick burst requirement to be a ductile failure mode for polyethylene gas pipe instead of a minimum pressure because it is more meaningful.
- Developed a new annex in D 2513 for polyamide pipe and fittings
- Wrote a new standard for polyamide butt fusion fittings (F 1733)
- Added 50-year substantiation for polyethylene materials to D 2513 for gas pipe
- Included pressure design basis protocol in ASTM D 2837
- Added polyethylene validation requirement to D 2837
- Included a crosslinked polyethylene pipe material designation code in F 876
- Wrote a new ASTM standard test method for rapid crack propagation based on the ISO standard (F 1583)
- Wrote a new ASTM standard test method for an 80°C notch pipe test based on the ISO method (F 1474)
- Introduced 80°C requirements for polyethylene heat fusion socket fittings (D 2683) and polyethylene butt fittings (D 3261) consistent with ISO TC 138 requirements
- Wrote a new ASTM test method to measure slow crack growth resistance of polyethylene materials used in corrugated pipe (F 2136)

3. Dr. Palermo led an ASTM workshop to review differences and similarities between the ASTM plastic pipe pressure rating method – D 2837 and the ISO plastic pipe pressure rating method – ISO 9080.

4. Dr. Palermo gave a "spotlight presentation" on ASTM F17.38 ISO standards activities during an ASTM Committee Week.

B. ISO

Dr. Palermo was chairman of the Technical Advisory Group (TAG) for ISO (International Standards Organization)/TC 138 for plastic pipe materials for over 10 years and has attended ISO meetings since 1983. As chairman, Dr. Palermo represented the US plastic pipe industry at all ISO/TC 138 meetings. Dr. Palermo also formulated the US position on all standards ballots from ISO/TC 138. Within TC 138, Dr. Palermo was primarily active in SC 2 for water plastic pipe, SC 4 for gas plastic pipe and SC 5 for plastic pipe test methods. Dr. Palermo has provided ISO liaison reports at various ASTM F 17 subcommittee meetings, and also provided ASTM F 17 liaison reports at ISO/TC 138 meetings.

C. HSB and PPI

Dr. Palermo became a member of the PPI Hydrostatic Stress Board (HSB) in 1985 and was chairman of the HSB for seven years. HSB is responsible for establishing the policy for pressure rating of plastic pipe materials in North America. While with PPI, Dr. Palermo continually updated both TR-2 and TR-4. TR-2 is a public listing of the various ingredients that are qualified for the PPI PVC generic formulation. TR-4 is a public listing of the pressure rating of plastic pipe materials obtained using ASTM D 2837. Dr. Palermo was also instrumental in listing the pressure rating of plastic piping materials obtained using the international pressure rating system (ISO 9080) in TR-4. These MRS (Minimum Required Strength) ratings were added to TR-4 in 1999. Under his leadership, the PDB (pressure design basis) for composite or multiplayer pipes and the SDB (Strength Design Basis) for molding materials were also added to TR-4. Dr. Palermo has attended PPI meetings since 1990 and served as the PPI Technical Director from 1996 until 2003.

D. AASHTO

Dr. Palermo has also assisted with revision of AASHTO standards for polyethylene corrugated plastic pipe used in highway applications. His key contribution was development of an ASTM test method to measure the slow crack growth resistance of the polyethylene material used in corrugated plastic pipe. Through a PPI task group, round robin testing was conducted to establish the precision of the test method known as NCLS (notched constant ligament stress). AASHTO now references this NCLS test as a requirement in their M 294 corrugated pipe standard.

E. CSA

Dr. Palermo is a member of CSA (Canadian Standards Association) B137 Technical Committee for plastic piping systems and also a member of CSA Z662 Clause 12 for gas distribution piping systems. Recent projects that Dr. Palermo has chaired are the addition of the MRS (Minimum Required Strength) ISO pressure rating method for PE 100 materials to B137 and the addition of RCP (rapid crack propagation) requirements to the gas pipe standard B137.4.

F. Plastics Pipes Conferences

Dr. Palermo has served on the Organizing Committee for Plastics Pipes XII held in Milan, Italy in 2004, for Plastics Pipes XIII held in Washington DC in 2006 and Plastics Pipes XIV, to be held in Budapest, Hungary in 2008.

G. GPTC

Dr. Palermo has been a member of the Gas Piping Technology Committee (GPTC) since 1995. GPTC provides guide material for the gas industry to comply with US Federal requirements for the gas distribution industry. Dr. Palermo has chaired several projects within GPTC.

H. TRB
Dr. Palermo has been attending TRB meetings since 1999, and has made several presentations at various committee meetings. Dr. Palermo is currently a member of the Committee on Subsurface Soil-Structure Interaction, AFS40.

VI. Plastic Pipe Industry Publications

1. E. F. Palermo and M. Cassaday, “Comparison of Water/Methane Stress Rupture Testing", AGA PMC Workshop (1982).

2. E. F. Palermo, "Aging of Plastic Pipe", AGA PMC Workshop (1983)

3. E. F. Palermo and I. K. DeBlieu, "Aging of Polyethylene Pipes in Gas Distribution Service", AGA Distribution Conference (1983).

4. E. F. Palermo and I. K. DeBlieu, "Compression Ring Environmental Stress Crack Resistance (Pipe) Precision and Accuracy Round Robin", ASTM Quality Assurance Symposium (1983).

5. E. F. Palermo, "Rate Process Method as a Practical Approach to a Quality Control Method for Polyethylene Pipe", Eighth Plastic Pipe Symposium (1983).

6. E. F. Palermo, “Plastic Piping Material", South Eastern Gas Association Meeting (1984).

7. E. F. Palermo and I. K. DeBlieu, “Rate Process Concepts Applied to Hydrostatically Rating PE Pipe", Ninth Plastic Pipe Symposium (1985).

8. E. F. Palermo, “Battelle Slow Crack Growth Test - DuPont Technical Position", AGA PMC Workshop (1986).

9. E. F. Palermo, “Impact Tests on Saddle Fittings to Determine Conformance to ASTM F905”, AGA Distribution Conference (1986).

10. E. F. Palermo, "New ASTM D 2513 Outdoor Storage Requirements", AGA PMC Workshop (1987).

11. E. F. Palermo, “Polyethylene Pipe for Gas Distribution - That Was Then, This is Now”, Irish Gas Association Centenary Conference (1987).

12. E. F. Palermo, “Plastic Pipe/Fitting Failure: Cause and Prevention", Pacific Coast Gas Association Workshop (1987).

13. E. F. Palermo, K. G. Toll, G. T. Appleton, "Using Laboratory Tests on PE Piping Systems to Solve Gas Distribution Engineering Problems", Tenth Plastic Pipe Symposium (1987).

14. E. F. Palermo, “Critical Evaluation of Rate Process Method 'Anomalies’”, AGA PMC Workshop (1988).

15. E. F. Palermo, K. Gunther, and M. Kanninen, "Progress Toward Designing PE Gas Pipe Against RCP (Rapid Crack Propagation)", AGA PMC Workshop (1989).

16. E. F. Palermo, "Large Diameter Plastic Pipe Damage Investigation", Midwest Gas Association Meeting (1989).

17. E. F. Palermo, K. Gunther, and D. VanDeventer, "Squeeze-Off of Large Diameter Polyethylene Pipe", AGA Distribution Conference (1990).

18. E. F. Palermo, “ASTM/ISO Rating Methods – bridging the gap across the waters”, Plastics Pipes IX (1995)

19. E. F. Palermo, “High Pressure Gas Distribution Piping System”, AGA Distribution Conference (1996).

20. E. F. Palermo, “Plastic Pipe Design Equation Update”, AGA Distribution Conference (1997).

21. E. F. Palermo and D. B. Edwards, “An Alternate Method for Determining the Hydrostatic Design Basis for Plastic Pipe Material”, Plastics Pipes X (1998)

22. E. F. Palermo, “Comparison of ASTM and ISO Gas Pipe Standards”, AGA Distribution Conference (2001).

23. E. F. Palermo, “PPI Adopts International Pressure Rating Method for Plastic Piping Materials”, Plastics Pipes XI (2001)

24. E. F. Palermo, “What’s New with ASTM, DOT and ISO?”, AGA Distribution Conference (2003).

25. E. F. Palermo and Jimmy Zhou, “Can ISO MRS and ASTM HDB Rated Materials be Harmonized”, Plastics Pipes XII (2004)

26. E. F. Palermo, “Correlating Aldyl ‘A’ and Century PE Pipe RPM Projections With Actual Field Performance”, Plastics Pipes XII (2004)

27. E. F. Palermo, “High Performance Bimodal PE 100 Materials For Gas Piping Applications”, AGA Distribution Conference (2005)

28. E. F. Palermo and Steve Swanstrom, “Reinforced Thermoplastic Pipe (RTP) for High-Pressure (800 psig) Gas Piping Applications”, AGA Distribution Conference (2006)

29. E. F. Palermo and E. Lever, “Innovative Methodology for Fitting Lifetime Prediction and Process Control by Correlating Rate Process Method Analysis of Molded Fittings with Notch Ring Test Data”, Plastics Pipes XIII (2006)

30. E. F. Palermo et al, “New Test Method to Determine the Effect of Recycled Materials on the Life of Corrugated HDPE Pipe as Projected by the Rate Process Method”, Plastics Pipes XIII (2006)

31. E. F. Palermo, “Using the CRS Concept for Plastic Pipe Design Applications”, Plastics Pipes XIII (2006)

32. E. F. Palermo and J. M. Kurdziel, “Stress Crack Resistance of Structural Members in Corrugated High Density Polyethylene Pipe”, Transportation Research Board (2007)

33. E. F. Palermo et al, “Effect of Elevated Ground Temperature (from Electric Cables) on the Pressure Rating of PE Pipe in Gas Piping Applications”, AGA Distribution Conference (2007)

34. E. F. Palermo and S. Chung, “Rate Process Method Applied to Service Life Forecast of PE Molded Fittings”, AGA Distribution Conference (2008)

35. E. F. Palermo, “What’s New With Plastic Pipes – An Overview”, Plastics in Underground Pipes 2008.

36. E. F. Palermo et al, “Increasing Importance of Rapid Crack Propagation (RCP) for Gas Piping Applications - Industry Status”, Plastics Pipes XIV (2008).

37. E. F. Palermo, “What’s New With Plastic Pipes – An Overview”, Plastics in Underground Pipes 2009.

38. E. F. Palermo et al, “Increasing Importance of Rapid Crack Propagation (RCP) for Gas Piping Applications - Industry Status”, AGA Distribution Conference (2010).

39. E. F. Palermo et al, “Peelable Polyethylene Pipe for Gas Piping Applications”, AGA Distribution Conference (2010).

40. E. F. Palermo, “Use of PE100 with a Minimum Required Strength (MRS) Rating in a Natural Gas Distribution System”, Plastics Pipes XV (2010).

41. E. F. Palermo, “Comparison Between PE 4710 (PE 4710 PLUS) and PE 100 (PE 100+, PE 100 RC)”, Plastics Pipes XV (2010).

42. E. F. Palermo et al, “CHANGES TO CSA Z662 “OIL AND GAS PIPELINE SYSTEMS” TO INCORPORATE HIGHER PERFORMANCE PLASTIC PIPE”, Plastics Pipes XV (2010).

43. E. F. Palermo, “How to Design Against Long Running Cracks in Plastic Pipe for Water Applications”, ASCE (2011).

Proposed Protocol for Managing Select Aldyl A Pipe in Avista Utilities' Natural Gas System

Attachment 9

January 13, 2009 Staff Memorandum Follow-Up Information Regarding 2005 Incident in Tucson, AZ

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COMMISSIONERS
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ARIZONA CORPORATION COMMISSION

DAVID RABER
Director, Safety Division

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Staff Memorandum

Arizona Corporation Commission

DOCKETED
JAN 13 2009
DOCKETED BY

To: THE COMMISSION DOCKET NO. G-01551A-07-0504

From: Safety Division

Date: January 13, 2009

RE: FOLLOW-UP INFORMATION REGARDING 2005 INCIDENT IN TUCSON, AZ.

In the Commission Open Meeting held on December 19, 2008 regarding G-01551A-07-0504, Commissioner Mayes requested an update from the ACC Safety Division, Pipeline Safety Section regarding an incident cited in the Recommended Opinion and Order, page 13. This memo is intended to respond to that request.

Background

As a result of an incident that occurred on July 25, 1991 which resulted in one fatality, Southwest Gas Corporation (SWG) was found to be in violation of CFR-49, 192.303, 192.305 and 192.319, all involving proper installation of pipelines.

Subsequent to this incident, SWG and the ACC entered into a Settlement Agreement (Docket # U-1551-91-372 / Decision #57718). The Settlement Agreement required SWG to identify and conduct investigations to determine the condition of all Polyethylene Aldyl HD pipeline in the SWG system. Decision 57718 also required SWG to conduct additional leak surveys, make repairs and replace all pipelines that were originally installed with improper backfill bedding and shading materials.

SWG submitted a plan to the Pipeline Safety Section for approval in accordance with Decision 57718 and began a systematic inspection, repair, and replacement program during 1992. By December 31, 1998, SWG had replaced 74 miles of Aldyl HD pipeline that had been identified as having injurious backfill materials used at the time of installation. SWG also conducted internal camera inspections on a total of 221 miles of 2"and 4" pipeline to check for improper fusions and possible impingement anomalies. A total of 7,016 fusions were either reinforced or replaced as a result of these activities.

Based on Pipeline Safety Section inspections and information provided by SWG it was determined in March 1999 that SWG had completed all tasks associated with Decision #57718. In addition to the pipeline replaced as required by the Order, SWG also replaced 648 miles of Aldyl-A PE, and 105 miles of ABS pipelines based on leak survey results.

Subsequent Incident in May 2005 which was referenced in the Rate Case (G-01551A-07-0504)

In May 2005, SWG responded to a reported gas leak and fire at 1841 S. Campbell, Tucson, Arizona. The incident resulted in injury to one individual as a result of the fire. The individual was transported to the hospital with severe burns.

Larry Ayers, Senior Pipeline Safety Investigator from the ACC Tucson Office, conducted an investigation to determine the cause of the fire. This investigation discovered that the pipeline failure and fire was due to a crack in the Polyethylene Aldyl HD pipeline caused by a rock impinging upon the pipeline. It was also noted in the investigation that the pipeline appeared to have been properly installed using proper trench and backfill materials. The rock impingement may have been the result of excavation activities not related to SWG operations. Following the incident, SWG replaced all remaining Aldyl pipeline in the vicinity of the failure. There were no violations issued to SWG as a result of this incident and the case was closed.

David Raber
Director

Robert Miller
Pipeline Safety Supervisor

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Attachment 10

April 11, 2011
Pipeline Safety Forum –
Aging Pipeline Infrastructure

BRIAN SANDOVAL
Governor

STATE OF NEVADA

PUBLIC UTILITIES COMMISSION

ALAINA BURTENSHAW
Chairman

REBECCA WAGNER
Commissioner

LUIS F. VALERA
Commissioner

CRYSTAL JACKSON
Executive Director

April 11, 2011

Honorable Secretary Ray LaHood
United States Department of Transportation
1200 New Jersey Avenue, SE
Washington, DC 20590

Re: Pipeline Safety Forum - Aging Pipeline Infrastructure

Dear Secretary LaHood:

The Public Utilities Commission of Nevada ("PUCN") via its Pipeline Safety Staff has been working with the Local Distribution Companies ("LDCs") in the State regarding the replacement of certain "aging" and "high risk" types of natural gas pipe for some time. To date the PUCN has never mandated a specific pipeline replacement program or enhanced maintenance activities, nor has the PUCN implemented any type of rate surcharge mechanism to facilitate pipeline replacement work.[1] This lack of a need for a mandated pipe replacement program (and rate surcharge) is largely due to the success the PUCN and its Staff have had in working with the jurisdictional gas LDCs to identify pipelines that have high leakage rates, compared to the norm for the state, and then to address the concerns associated with those pipelines in a judicious and cost effective manner.

These efforts over the past 12-15 years have led to PVC and Aldyl A/HD PE plastic pipe being subject to annual leakage surveys outside of designated business districts in excess of the 5 year leakage survey requirement in the code, implementation of integrity management analysis via equations/algorithms to identify pipe that warrants enhanced monitoring or replacement, and extensive replacement of such problematic pipelines.

For example, as of the end of 2010:

1. NV Energy North (Reno area) has replaced roughly 250,000 linear feet ("lf") of bare and coal tar coated pipe, which includes all known bare steel pipe in their system, and expects to

[1] The PUCN currently has a Docket pending before it (Docket No. 11-03029) in which Southwest Gas Corporation ("SWG") is requesting special accounting treatment of costs associated with certain enhanced reliability and PVC pipe replacement projects that SWG is accelerating construction of this year.

complete replacement of its remaining coal tar coated steel pipe in the next 5 to 7 years. With these replacements NV Energy North will be left with a very small amount of pre-1963 steel pipe and none of a vintage prior to 1957. As part of a 2011 general rate case proceeding, the PUCN authorized NV Energy North to begin recovering the first set of costs associated with the replacement of this coal tar coated pipe.

2. The future plan is for NV Energy North to focus on replacing all remaining pre-1963 steel pipe before switching its focus to pre-1967 steel pipe, as all steel pipe installed in 1967 and later had Xtru coat polyethylene plastic coating and cathodic protection ("CP"), via anodes, at the time of the original installation.

3. SWG (Las Vegas and Carson City areas) has replaced approximately 6,400,000 lf of the approximately 9,600,000 lf of PVC plastic mains and services installed prior to 1975. In 1975 SWG switched to PE pipe for its plastic mains and service. It is the hope of the PUCN Staff that all PVC mains and services will be replaced in or around the 2020 time period.

4. SWG has replaced in excess of 250,000 lf of pre-code (pre-7/1970) steel main and services, including all bare steel mains and services.

5. SWG has replaced a significant amount of Aldyl A medium-density PE and Aldyl HD high-density PE installed by CP National in the City of Henderson since SWG acquired the system from CP National in 1991.

6. The PUCN Staff has confirmed that cast/wrought iron or ductile iron pipe was either never installed in Nevada or was replaced long ago. Additionally, no CAB, ABS or PB plastic was ever installed in Nevada, and all bare steel pipe that had been installed has now been replaced.

The PUCN Staff is also now working with the LDCs on a detailed review of the situation with steel pipelines operating at pressures above 100 psig, including distribution piping operating at elevated pressure, low stress transmission pipelines (operating at pressures that produce a hoop stress between 20% and 30% of SMYS), and high stress transmission pipelines (operating at pressures that produce a hoop stress at or above 30% of SMYS). This effort will help define how much and what type of high pressure ("HP") piping there is in the state, the vintage and era of the pipe installations, what level of integrity management planning is being applied to each type of HP piping, and what percentage of high stress transmission piping can currently accommodate the insertion of "smart pigs" and what is being done to increase this percentage.

Additionally, in 2007, the Nevada Legislature passed one of the Country's most aggressive One-Call/Third Party Damage Laws and gave authority for monitoring and enforcing that One-Call Law to the PUCN and its Pipeline Safety Staff. Since the passage of that One-Call Law, Nevada has seen its third-party damage rates drop by more than 80 percent. With third-party damage being the single greatest risk to pipeline infrastructure, Nevada's One-Call law has be instrumental in keeping the public safe and the gas systems in the State operating reliably.

The PUCN appreciates the opportunity to provide input to the upcoming forum regarding the safety and integrity of the nation's pipeline infrastructure.

Yours truly,

Crystal Jackson
Executive Director
Public Utilities Commission of Nevada

Proposed Protocol for Managing Select Aldyl A Pipe in Avista Utilities' Natural Gas System

Attachment 11

PG&E to replace more than 1,200 miles of faulty gas piping across California

PG&E to replace more than 1,200 miles of faulty gas piping across California

Oct. 14, 2011

Facing pressure after a leaky plastic gas pipe sparked a fire at a Cupertino condominium complex, PG&E has decided to replace all 1,231 miles of the same type of aging and notoriously faulty pipeline spread across the state.

The massive project will start next month in Cupertino and Roseville -- where the pipe has been involved in recent accidents -- and in St. Helena. Communities across Northern California and in every Bay Area county will be dug up while the job, expected to cost hundreds of millions of dollars, is completed over the coming years.

Unlike the 30-inch steel transmission gas line that ruptured last year, killing eight people in San Bruno, the 2-inch wide plastic pipe that failed in Cupertino six weeks ago is part of PG&E's network of 42,000 miles of distribution lines that deliver gas directly to businesses and homes.

Batches of that plastic pipe, manufactured by DuPont (DFT) before 1973 under the name Aldyl-A, have shown a history of cracking, prompting numerous federal safety advisories dating to 1998.

"This is the oldest vintage. We know it is predisposed to cracking," Jane Yura, PG&E's vice president of standards and policies for gas operations, said in an interview Thursday. "We are looking at what we need to do to remove the risks and run a safe system."

Replacing all 1,231 miles of PG&E's pre-1973 Aldyl-A pipe will take more than three years, Yura said. She said PG&E will go to the California

Public Utilities Commission, probably next year, to ask for a rate increase to cover the cost, which she said the company had not finished estimating yet.

The company also is building computerized maps to digitize 15,000 paper maps showing where the pipe is located statewide. It is building a database to help analyze leaks and find which sections should be replaced first, Yura added. And it will replace some of the 6,676 miles of Aldyl-A pipe built after 1973 in areas with higher-than-normal leak histories, she said, even though that vintage of pipe has not been the subject of federal advisories.

No federal or state law requires PG&E to dig up all of its Aldyl-A pipe. But problems across the country with it have resulted in numerous lawsuits and multimillion-dollar settlements, dating back decades.

"They know they have 1,200 miles of old, worn out, defective pipe," said Jim Findley, of San Rafael, a PG&E gas measurement and control mechanic for 38 years who has raised safety issues about Aldyl-A pipe at PG&E shareholder meetings.

"Sooner or later, this is going to pop up on some attorney's or law firm's screens, and they are going to be going after PG&E for not doing due diligence."

In 2008, a section of an Odessa, Wash., natural gas pipeline made of Aldyl-A pipe exploded, causing a fire that injured two people and destroyed buildings. The faulty pipes were also blamed for a 2003 explosion that killed a Missouri fairgrounds employee. And in 2000, Arizona's Tucson Gas & Electric reached a $25 million settlement, after problems occurred with its Aldyl-A plastic gas pipeline, installed in the 1960s and 1970s.

Locally, PG&E found numerous leaks in pipes at the Northpoint condominium complex in Cupertino after an Aug. 31 fire gutted a woman's home only 15 minutes after she had left.

Then, on Sept. 27, another Aldyl-A distribution line failed under a Roseville intersection, sending flames shooting into the air for seven hours.

Findley called PG&E's new strategy "a positive step" and said it would make PG&E one of the only major utilities in the nation to remove all of its pre-1973 Aldyl-A pipe.

"This will take at least 10 years to get that much pipe out of the ground. And hundreds of millions of dollars," Findley said. "I don't see any way it will be less than $1 billion. There are sidewalks and roads, storm drains, things like that, and you have to work around all of it. Because PG&E hadn't been taking care of business, now they are behind the eight ball."

In 1998, after a similar type of plastic pipe cracked in Waterloo, Iowa, causing an explosion that destroyed a bar and killed six people, the National Transportation Safety Board recommended utilities and state regulators better monitor plastic piping from that era and replace it when they find it to be a risk.

In 2002, and again in 2007, the federal Pipeline and Hazardous Materials Safety Administration issued advisory bulletins warning of "premature brittle-like cracking" in Aldyl-A pipes made before 1973 and urging utilities to review records and more frequently survey the lines for leaks. But under pressure from industry, neither the federal government nor the California Public Utilities Commission has ever required it all to be dug up and replaced.

Attempting to turn the page after last year's San Bruno disaster, PG&E hired a new CEO, Anthony Earley, a former Naval officer who ran a Detroit utility, DTE Energy, and brought in a new executive vice president in charge of gas operations, Nick Stavropoulos, who overhauled gas line safety at utilities in New York and New England. In his prior job, Stavropoulos replaced Aldyl-A piping across New Hampshire.

"This is good news. I'm happy that they are planning to replace it," said Assemblyman Jerry Hill, D-San Mateo, of PG&E's new plans. "I'm troubled by the fact that it took the recent tragedies for them to realize that this needs to be replaced. But I'm happy that they are doing it."

Earlier Thursday, Hill and Assemblyman Paul Fong, D-Mountain View, announced plans to introduce legislation next year requiring the Public Utilities Commission to force PG&E and other utilities to adopt recommendations from the National Transportation Safety Board for improving natural gas pipeline safety.

Hill said he isn't sure how much ratepayers should pay for PG&E's work to replace its oldest Aldyl-A lines.

"I question whether the ratepayers should be held responsible," Hill said. "We paid for that pipe once. I don't know what the life expectancy of that pipe was. But if it was more than 30 years, at least some of the cost should be the manufacturer's or PG&E's responsibility."

Contact Paul Rogers at 408-920-5045.

California not alone

Problems with the plastic pipe, manufactured by DuPont before 1973 under the name Aldyl-A, have been reported across the U.S.

1,231 miles

Aldyl-A pipe fabricated before 1973 still in PG&E's gas distribution network. The company says it will replace all of it.

6,676 miles

Aldyl-A pipe fabricated after 1973 in use by PG&E; this type has not been deemed unsafe, but the company will replace some of it anyway.

How much will it cost?

Unknown, but PG&E gas

measurement and control mechanic Jim Findley said,

"I don't see any way it will be less than $1 billion."

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Attachment 12

Letter to The Honorable Ray LaHood Secretary, U.S. Department of Transportation

Title: Letter to The Honorable Ray LaHood Secretary, U.S. Department of Transportation
Date: 10/17/2011
Location: San Mateo, CA
Letter
Congresswoman Jackie Speier (D-San Francisco/San Mateo) today released a letter to Secretary Ray LaHood, U.S. Department of Transportation, in which she asks that he direct PHMSA to require natural gas operators to remove pre-1973 Aldyl-A pipe from service.

The letter is below.

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October 17, 2011

The Honorable Ray LaHood
Secretary, U.S. Department of Transportation
1200 New Jersey Avenue, SE
Washington, DC 20590

Dear Secretary LaHood:

I respectfully request that you direct PHMSA to take immediate action to address the long-known safety risks associated with pre-1973 Aldyl-A plastic pipe manufactured by DuPont. Specifically, I believe natural gas operators should remove this pipe from use in this country.

As you well know this pipe, used in natural gas distribution lines through the nation, has been prone to cracking caused by freezing temperatures and earth movement. Most recently there have been two natural gas explosions in Northern California that involved pre-1973 Aldyl-A pipe. The operator, PG&E, has announced that it will seek approval from the CPUC to replace all 1,231 miles of pre-1973 Aldyl-A pipe from its system. I commend PG&E on this step and am hopeful that it will propel the appropriate response from PHMSA and natural gas operators.

DuPont first issued warnings about the failure aspects of this pipe in 1982 and the NTSB recommended close monitoring and replacement of the pipe when necessary in 1998, following an Aldyl-A pipe explosion that killed six people in Waterloo, Iowa. Finally, in 2007 PHMSA recommend closer monitoring of the pipe, but fell short of putting operators on a removal schedule. The time to get pre-1973 Aldyl-A pipe out of the ground is now.

You, Mr. Secretary, appreciate better than anyone else how unlikely it will be to get Congressional action on this issue anytime soon. Although the NTSB recommendation has been on the books for more than 10 years, Congress has sat on its hands. You can do what 535 members of Congress can't or won't do. You can propose regulations to begin a systematic removal of this flawed and dangerous plastic pipe immediately. I hope you will.

All the best,

Jackie Speier
Member of Congress