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Field Installation and Aging Characteristic Evaluation of PA11 Piping Systems at Elevated Pressures

Nashville Gas

Prepared for: **Atofina Chemicals**

Prepared by Dennis R Jarnecke
Gas Technology Institute
Des Plaines, Illinois

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Executive Summary

The natural gas industry has long understood the advantages associated with plastic piping materials. In addition to being easier to handle and join, plastic piping materials eliminate the need for long term corrosion control and the associated costs This is evident by the exponential increase in the amount of plastic pipe that has been installed in the past decade. At present, the majority of the new installations utilize polyethylene piping materials at pressures up to 100 psig.

Since the mid-1990's, there has been an on-going effort to utilize the plastic piping system at higher operating pressures The American Gas Association Plastic Materials Committee (AGA-PMC) has sponsored several petitions to the Department of Transportation Office of Pipeline Safety (DOT OPS) to allow the use of the high density PE materials at increased pressures up to 124 psig. Concurrently, the industry has also sponsored research into new materials that can operate at pressures up to 230 psig while maintaining the overall benefits of plastic piping materials. One of the most promising candidates is polyamide 11 (PA11).

During the late 1990's, the Gas Technology Institute (GTI) along with several utilities initiated a comprehensive research study to determine the feasibility for the use of PA11 at higher operating pressures for natural gas distribution applications. As part of the overall program, the PA11 piping systems (pipe and appurtenances) were subjected to comprehensive laboratory testing and field evaluations. The cumulative results of the laboratory testing and field evaluation validated the ability for PA11 piping systems for use at higher operating pressures in a safe and reliable manner. Based on the positive results of the study, a waiver was filed and successfully attained from both the Illinois Commerce Commission and the Department of Transportation Office of Pipeline Safety. During December 1999, the first ever installation of PA11 piping systems in the public right of way at Nicor Gas was successfully completed, and the system has not had any adverse operating performance issues.

In order to be proactive, GTI with support from several utilities has initiated a secondary research program to address the impact of various geographic and climatic environments on the PA11 piping systems operating at higher pressures. This includes environments that are moisture rich ("swampy" areas), high temperature, rocky soil, etc.

One site selected to test and evaluate the PA11 piping system was planned at Nashville Gas (a Piedmont Natural Gas Company) The objective of this installation was to evaluate the performance of PA11 in rocky soil conditions, to increase the range of operating pressures (up to 175 psig), and to evaluate the ability to install coiled PA11 pipe. During May 2003, the installation was completed without any major problems. After approximately one year in operation, a sample of 2" PA11 pipe was removed for testing and evaluation. This removal took place on May 18, 2004. This report summarizes the technical considerations pertaining to the safe installation of PA11 piping

systems within Nashville Gas' distribution network and the results of the testing on the one year aged samples of PA11 pipe.

Background

During 1999, GTI with the support of Nicor Gas, planned and executed the first ever installation of PA11 piping systems in the public right of way operating at 150 psig under a waiver from both the Illinois Commerce Commission and Department of Transportation – Office of Pipeline Safety. However, the Nicor Gas waiver did not permit the use of a 0.40 design factor and was limited to a class 1 location. To date, Nicor Gas has not experienced any problems with the PA11 piping system. Aging characterization studies to quantify the effects of in-service conditions have demonstrated no adverse effects to the PA11 piping system.

In order to further test and evaluate the PA11 piping system, an installation was planned at Nashville Gas. The objective of this installation was to evaluate the performance of PA11 and to increase the range of operating pressures up to 175 psig.

Waiver Process

The safe use of plastic piping systems are governed by 49CFR Part 192 of the Code of Federal Regulations which set forth the minimum standards that must be adhered to by all LDCs. In particular, plastic piping cannot operate at pressures greater than 175 psig and subjected to the use of a 0 32 design factor in the Barlow formula contained within Section 192.121.

Given the positive experience of the prior installations at Nicor Gas and Atmos Energy - Louisiana, and prior waiver approvals for PA11 in Illinois and Arizona a waiver was drafted to eliminate certain restrictions in order to further test and evaluate the PA11 piping systems in future commercial applications. Specifically the waiver requested the following:

- Allow operation of PA11 at pressures greater than 100 psig
- The use of PA11 at operating pressures as limited by its hydrostatic design basis
- The use of a 0.40 design factor instead of the 0.32 design factor within the Barlow formula used to calculate operating pressure
- The use of "hot-tapping" (tapping against the pressure main) given that the site selection was in a conversion area
- Maximum design pressure of 175 psig

The waiver was submitted to the Tennessee Regulatory Authority (TRA) during September 2001. A formal public hearing was held on May 7, 2002 to affirm the waiver and the final order from the TRA was received on June 17, 2002 (Docket No: 01-01133).

The approved waiver was sent to the Department of Transportation Office of Pipeline Safety and was accepted on August 26, 2002 without restrictions.

It is important to underscore the significance of this particular waiver. In addition to allowing the use of plastic piping systems at operating pressures greater than 100 psig, the Nashville Gas waiver was the first ever approval for the use of a 0.40 design factor.

Installation Details

The first step in any installation is to ensure compliance with all the respective regulations. Given that the PA11 piping material was a new material to Nashville Gas, all of the operators were first qualified to join PA11 piping materials. Each operator performed several fusions and subsequent fusions were tested using the bend back test in the presence of TRA pipeline safety personnel. Consequently, each operator was qualified to fuse PA11 pipe. The initial fusion qualification training was performed during August 2002 and the operators were re-qualified on March 31, 2003 just prior to the installation.

A schematic of the installation is shown below:

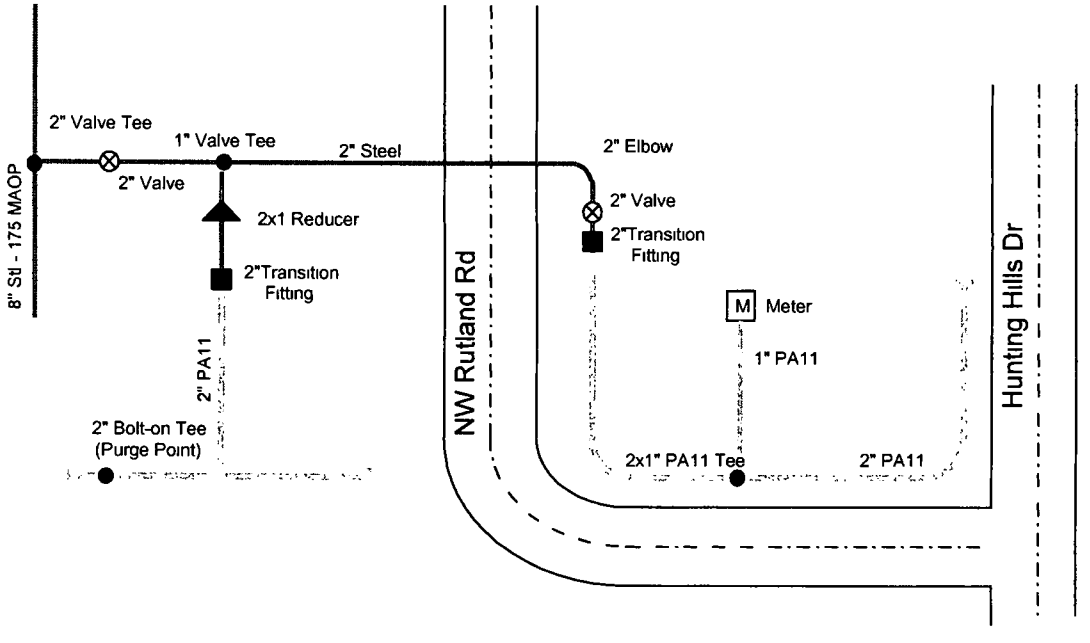

Figure 1: Nashville Gas Public Right of Way Installation Schematic

The installation is in a class 3 location serving 8 customers to date. Approximately 5723 feet of 2-inch SDR11 PA11 main was installed using open cut technique. Approximately 2437 feet of 1-inch IPS SDR11 pipe was use to serve the customers up the house meter set.

A 2-inch valve tee was installed to the 8-inch steel line, which operates at 175 psig. The 2-inch steel line was extended below NW Rutland Rd. One of the conditions throughout all of the installations is the removal of pipe sections at periodic intervals to evaluate the effects of in-service conditions. A test leg was constructed using a 1-inch valve tee on top of the 2-inch steel main prior to crossing Rutland Rd A 2x1" steel reducer coupling was installed and a small piece of 2-inch steel was installed A 2-inch steel to PA11 transition fitting was installed to facilitate the transition to PA11. Approximately 10 feet of PA11 was installed and connected to a 3-way PA11 tee, an additional 10 feet of PA11 pipe was installed in both directions from the 3-way tee to serve as the test pipe after 12 and 24 months of service A 2-inch bolt-on mechanical tee was installed to serve as the purge point for the test loop.

After the road crossing, a 2-inch valve was installed in order to isolate the test loop and a transition fitting was installed to extend the project using PA11 piping. Approximately 4300 feet of PA11 pipe (40 feet sticks) was installed following the curvature of Rutland Rd. It is important to note that no PA11 elbows (90°) were used in this installation. The entire PA11 pipe was subjected to bend radius of the street crossings.

2"x1" mechanical tees with a heat fuse outlet were installed on to the PA11 main and 1-inch PA11 pipe was fused from the outlet of the tee to the house meter sets operating at 175 psig

Following the turn towards Mt. Juliet Rd, an additional 1000 feet of 40 foot stick pieces of PA11 pipe were heat fused and installed. An additional 500 feet of coiled 2-inch PA11 was installed for the final stretch An inverted 2-inch steel-PA11 transition fitting was installed along with appropriate end connections to facilitate the purge

Once installed, the PA11 piping system was subjected to a pressure test. One on the main points of the waiver was to pressure test the installation at two (2) times the operating pressures versus the 1.5 times required by the code As a result, the entire line was pressurized to 350 psig and allowed to remain under test for 72 hours. The pressure was reduced and the line was purged using conventional purging practices and the installation was live on April 23, 2003 operating at 175 psig with three (3) service lines on that day. Additional service lines have been installed since.

A PLCS coiled pipe trailer and 2-inch pipe straightener were used to uncoil the coiled PA11 pipe. One – 500 foot coil of 2-inch PA11 was installed on the trailer. A backhoe was used to pull the pipe off of the trailer and through the straightener The use of the coiled pipe greatly increased the speed at which the pipe was installed. Butt fusions are only required every 500 feet instead of every 40 feet as with the stick pipe.

Appendix A contains several illustrations from the Nashville Gas PA11 field installation.

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Aging Properties of PA11 Pipe

U.S DOT has indicated that it will be necessary to install and evaluate the performance of PA11 high-pressure gas distribution pipe for DOT to consider accepting its use by the U.S natural gas industry. This will need to include a demonstration of the installation process, the availability of tools, equipment and written procedures to safely install and operate a PA11 natural gas high-pressure distribution system, and an analysis of the effect of long-term burial on material properties The installation at Nashville Gas presented an excellent opportunity to study the high pressure and rocky soil characteristics of PA11 piping materials.

One of GTI's tasks is to excavate and remove selected sections of the buried 2-inch PA11 pipe after 12 months and 24 months of use in a high-pressure natural gas distribution system to evaluate material aging of the pipe. The aging tests may include one or more of the following as needed to accurately determine the effect of in-ground usage on the PA11: quick burst, LTHS, tensile, and apparent tensile testing.

PA11 Pipe Removal (12 months)

The Nashville Gas removal of the 2-inch PA11 pipe from the test section leg took place on May 18, 2004; about twelve months after being installed and pressurized with gas. Approximately 10 feet of pipe was removed for testing purposes. The test leg was valved off to control the flow of gas pressure and a new section of 2-inch PA11 was reinstalled and pressurized

Appendix B contains several photos from the Nashville Gas 12 month pipe removal.

12 Month Results

Several samples were shipped to GTI for testing. Moisture levels found in the removed samples were 1.214% (a level about equal to the first removal at Nicor Gas). One specimen was prepared for "quick burst" testing; six specimens were die cut for tensile testing; and three specimens were prepared for long term sustained pressure testing (LTHS)

Dimensional Analysis

The dimensions of the plastic piping system are based on the Iron Pipe Size (IPS) or the Copper Tubing Size (CTS). The dimensions and tolerances of the PA11 pipe were tested in accordance to ASTM D2122 entitled *"Determining Dimensions of Thermoplastic Pipe and Tubing"* This standard covers the procedure for determining the outside diameter, minimum wall thickness, ovality, and the eccentricity range. These results (table 2) are compared to ASTM D2513 entitled *"Standard Specification for Thermoplastic Gas Pressure Pipe, Tubing, and Fittings"*

Measurements of the outside diameter and wall thickness were taken on the 2-inch IPS aged PA11 pipe removed from service on May 18, 2004.
Table 2 below summarizes the dimensional analysis of the 2-inch PA11 pipe removed from service on May 18, 2004

Pipe Size (in)	Average Min. Wall Thickness (in)	Average Outside Diameter (in)	Avg. Eccentricity Range	Average % Ovality
2 IPS	0 216 (±0 026)	2 375 (±0 006)	12	5

Table 1 Dimensional requirements per ASTM D2513

Average Min. Wall Thickness (in)	Average Outside Diameter (in)	Avg. Eccentricity Range	Average % Ovality
0 222	2 392	5 397	0 056

Table 2 Dimensional analysis results for PA11 removed after 12 months from Nashville Gas

Minimum Hydrostatic "Quick Burst" Testing

One 18" specimen was subjected to "quick bust" testing per ASTM D1599 "*Standard Test Method for Short-Term Hydraulic Failure Pressure of Plastic Pipe*".

The specimen was dimensionally measured and conditioned in a liquid bath at 73°F for one hour prior to testing. The sample was then pressurized internally with water and the pressure was increased uniformly until failure
The test results after more than 12 months of in service exposure is in Table 3 below.

Specimen Id	Minimum Wall (inch)	Outside Diameter (inch)	Time To Failure (seconds)	Maximum Pressure (psig)	Hoop Stress (psi)	Burst Setting (Rate Control)	Failure Mode/Comments
NG 3-04	0 222	2 392	64 2	1255 5	6136 115	38	Ductile
			Average =	1255.50	6,136.11		Date 7/24/04
			Std Dev. =	#DIV/0!	#DIV/0!		Technician Peter P Mulligan

Table 3 12-Month Aged PA11 "Quick Burst" Data

ASTM D2513-96a requires that the PA11 pipe fail in a ductile mode at a hoop stress exceeding 3900 psi. The removed section of pipe after more than12-months of in-service exposure with a hoop stress value of 6,136 psi still surpasses the allowable requirements.

Tensile Testing

Tensile properties for the PA11 material were obtained utilizing ASTM D638 entitled "*Tensile Properties of Plastics*". This particular test method includes determining the tensile properties of plastics by performing tests on standard specimens under controlled conditions of specimen preparation, temperature, humidity, and testing machine speed.

Six samples from the 12-month in-service pipe removed from Nashville Gas were die-cut in the form of a "Type I" specimen. Each of the specimens was conditioned at 74°F and 50% relative humidity for at least 48 hours prior to testing Measurements were taken for the width and thickness for each specimen and placed in the testing fixture. The testing speed was 2 inches/minute.

The data are summarized in Table 4

Operator MTS Test Date 6/18/2004
Method MTS ASTM D 638 Tensile Properties of Plastics - Extensometer-Crosshead (High Elongation)GTI msm Room Temp _____
Specimen Results:

Specimen #	Width in	Thickness in	Load At Yield lbf	Stress At Yield psi	% Elongation @ Yield %	Break Load lbf	Break Stress psi	Percent Elongation at Break %
1	0 470	0 229	598 414	5559 917	29 411	814 878	7571 098	235 297
2	0 468	0 232	653 123	6015 346	27 569	834 365	7684 612	261 219
3	0 468	0 219	598 676	5841 191	28 211	814 067	7942 728	258 165
4	0 468	0 225	621 256	5899 866	28 752	825 175	7836 418	246 630
Mean	0 468	0 226	617 867	5829 080	28 486	822 121	7758 714	250 328
Std Dev	0 001	0 006	25 827	193 478	0 784	9 602	163 900	11 827

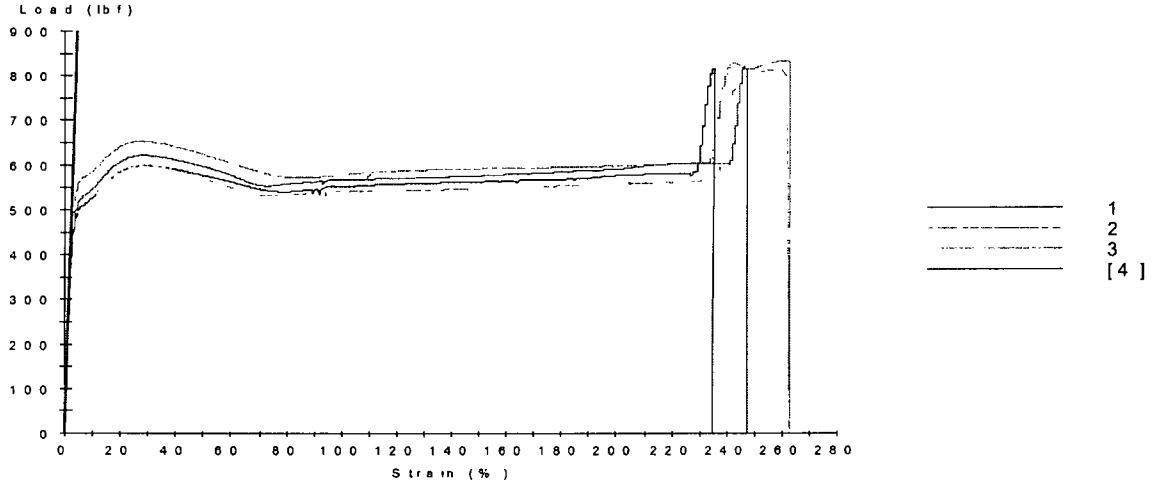

Table 4 Tensile Test Data (table and graph)

The average tensile strength at yield for the aged PA11 pipe removed from Nashville Gas' system was 5,829 psi and 250% elongation at break (28.49% elongation at yield)

Apparent Tensile Test

The apparent tensile strength measurement, in accordance to ASTM D2290, provides an excellent degree of correlation with the hydrostatic quick burst measurements. This test method determines the comparative tensile strength of plastics by performing tests on split ring disks under controlled conditions of specimen preparation, temperature, humidity, and testing machine speed.

Five specimens of the 2-inch IPS aged PA11 pipe were conditioned at 73°F and 50% humidity for a minimum of 24 hours prior to testing The specimens were prepared to conform to ASTM D2290 specifications for specimen thickness (0.50 in) and reduced wall thickness (0.250 in.). The specimens were placed within the test fixtures and pulled at a rate of 0.50 in/min. Per ASTM D2513-96a Annex A5, the minimum apparent tensile strength at yield shall be greater than 3900 psi. The results of the testing are summarized in table 5

Sample No.	Tensile Strength at Yield (psi)
1	6696
2	6719
3	6533
4	6548
5	6643
Average	6627 80
Std Dev	84 4908

Table 5 Apparent Tensile test results

Long Term Sustained Pressure Testing

PA11 currently has a PPI HDB rating of 2500 psi at 73°F, which is twice that of PE (1250 psi at 73°F). In order to verify the influence of in-service conditions on the PA11 pipe material, three specimens removed from service at Nashville Gas after 12-months were subjected to long term sustained pressure testing. This testing is performed per ASTM D1598 entitled *"Time to Failure of Plastic Pipe Under Constant Internal Pressure"*. Each sample was subjected to a hoop stress of 1850 psi (370 psig) of internal pressure in a water bath of 80°C.

For comparison, six specimens from the same lot of pipe not placed in-service were also tested (see table 6)

Specimen Id	Minimum Wall (inch)	Average O.D. (inch)	Maximum Pressure (psig)	Hoop Stress (psi)	Condition Temp. °C	Time To Failure (Hours)
A1	0 221	2 375	370	1803 1	80	919 7
A2	0 229	2 372	370	1731 2	80	2636 2
A3	0 226	2 375	370	1759 1	80	1009 2
A4	0.224	2 375	370	1776 5	80	2382 5
A5	0 224	2.378	370	1779 0	80	2462.0
A6	0 222	2 379	371	1802 4	80	1317 7

Table 6 Long Term Sustained Pressure Test Results of Control Pipe

Specimen ID	Minimum Wall (inch)	Average O.D. (inch)	Maximum Pressure (psig)	Hoop Stress (psi)	Test Temp.	Time to Failure
NG 1-04	0 223	2 391	370	1798 6	80°C	661 4 hrs
NG 2-04	0 222	2.392	370	1808 30	80°C	314 2 hrs
NG 4-04	0 221	2 392	370	1817 40	80°C	575 2 hrs

Table 7 Long Term Sustained Pressure Test Results of Aged Pipe (Nashville Gas)

The three specimens removed from the field after more than 12 months were tested under the identical stress state (see table 7) as the control specimens. The three samples removed from the field after 12 months failed prior to 1000 hours, however, ASTM requires the specimens surpass 170 hours at 80 C and a hoop stress of 1850 psi. Therefore, a failure prior to 1000 hours is not an indication of material aging. All specimens removed from Nashville Gas exceeded the 170 hours. With that said, it can be reasonably inferred that the PA11 pipe sections removed from service after 12 months are still consistent with the control samples (not in-service pipe).

Conclusions

As LDC's continue to seek out new materials and push towards changing the code of federal regulations in order to maximize their assets, comprehensive testing and evaluation is necessary to ensure continued safety and reliability of the overall gas distribution network. To that end, GTI with support of several utilities has planned and executed a program to validate the use of PA11 at higher operating pressures throughout the United States.

Based on previous successful installation experiences at Illinois (Nicor Gas), and Louisiana (Atmos Energy), the Tennessee (Nashville Gas) installation was planned to test the range of operating pressure for PA11 piping materials based on its current HDB

rating. During May 2003, more than 5700 feet of 2-inch and 2700 feet of 1-inch PA11 pipe was installed and is operating safely at 175 psig.

The most significant implications of this installation are.

- Approval for the use of a 0.40 design factor in the United States for plastic piping material
- 175 psig internal pressure
- Use of coiled PA11 pipe
- Conventional operating practices specific to PE can be readily extended to PA11
- The use of "hot-tapping" (tapping against the pressure main) given that the site selection was in a conversion area

The PA11 pipe samples removed after one year of in-service conditions were shipped to the Gas Technology Institute for testing and evaluation. All testing indicated that the piping material is performing as expected. Additional pipe will be removed from the Nashville Gas site after two years of being in-service and additional testing and evaluation will be conducted.

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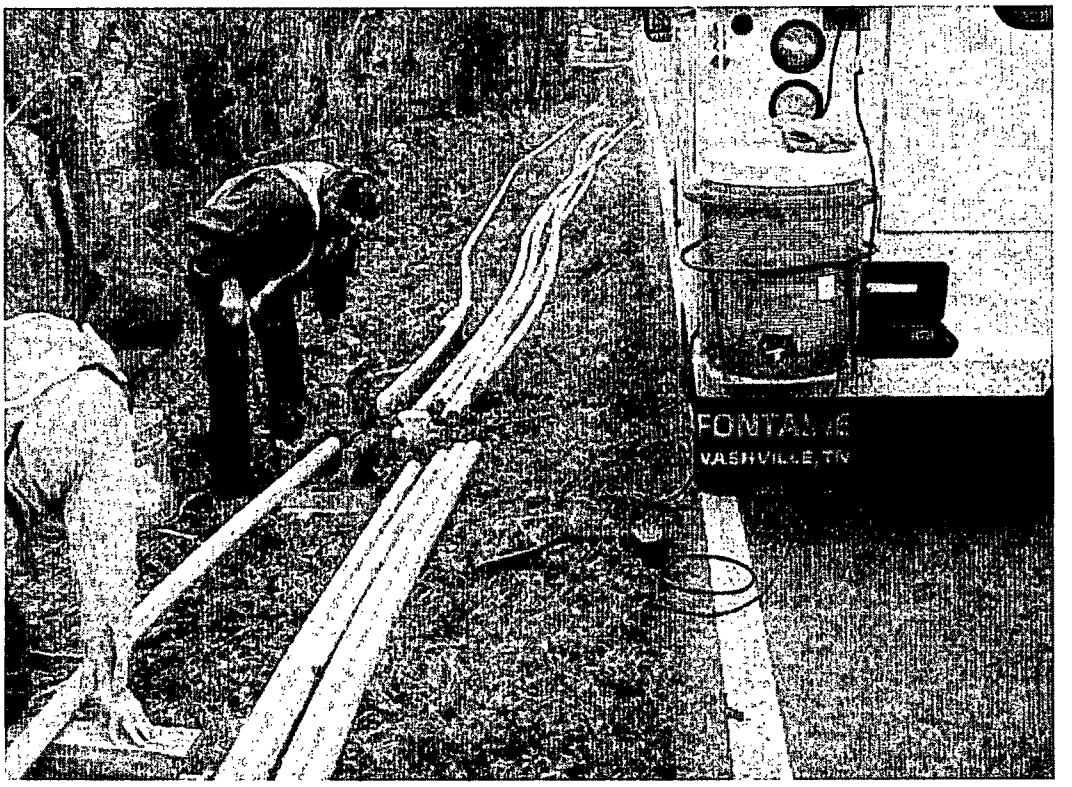
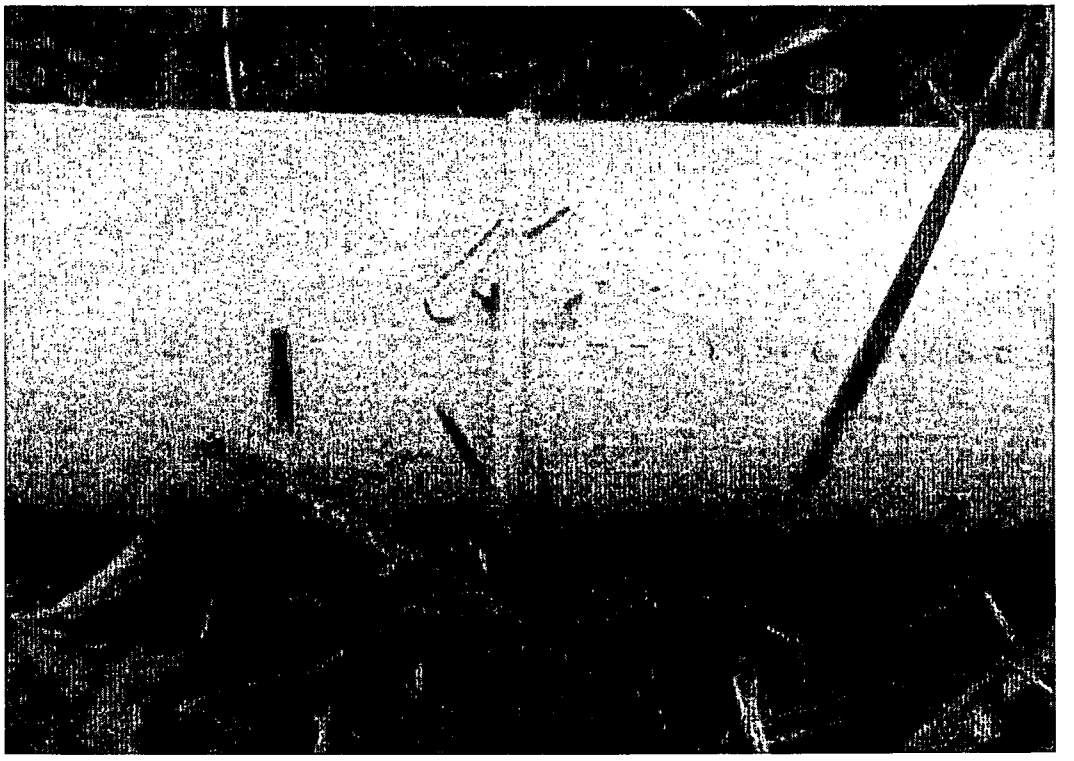
Appendix A

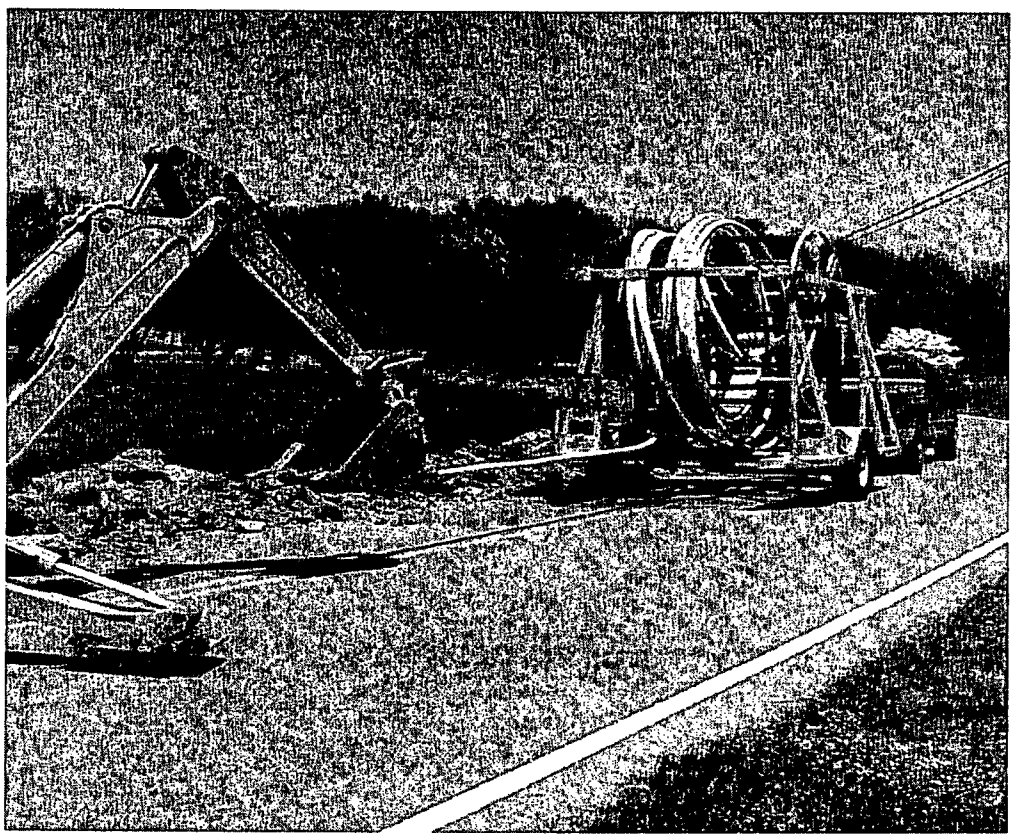


Fusing 40' sticks of PA11 pipe for the Nashville Gas installation



2" PA11 fused pipe

Installing PA11 pipe in an open trench



Installing a 500' coil of 2" PA11 pipe

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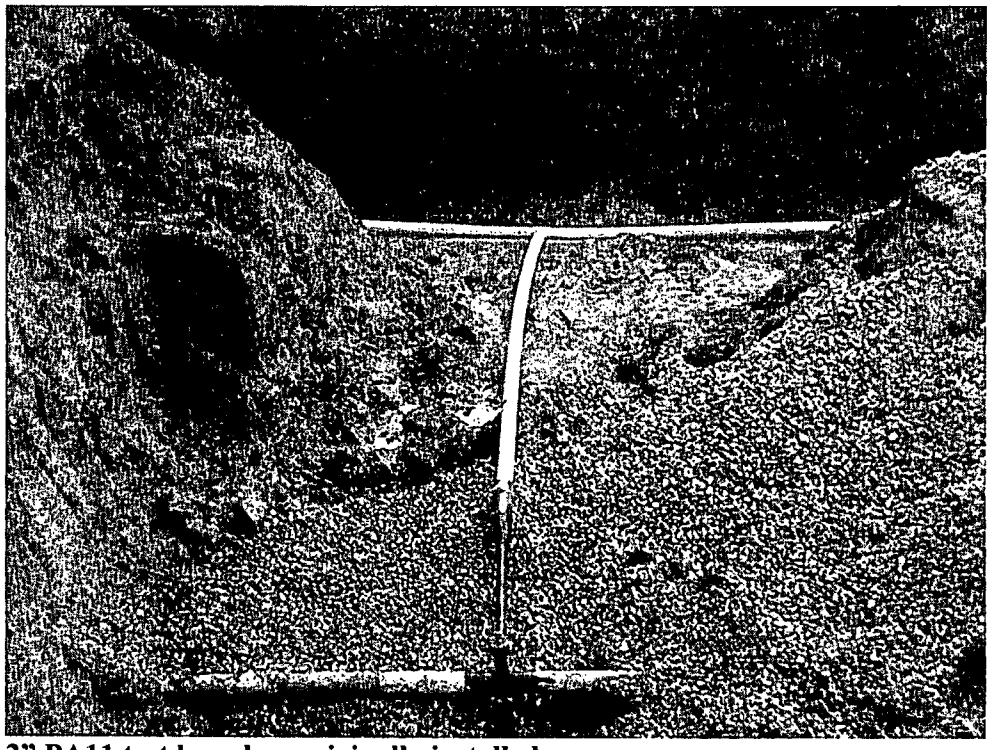
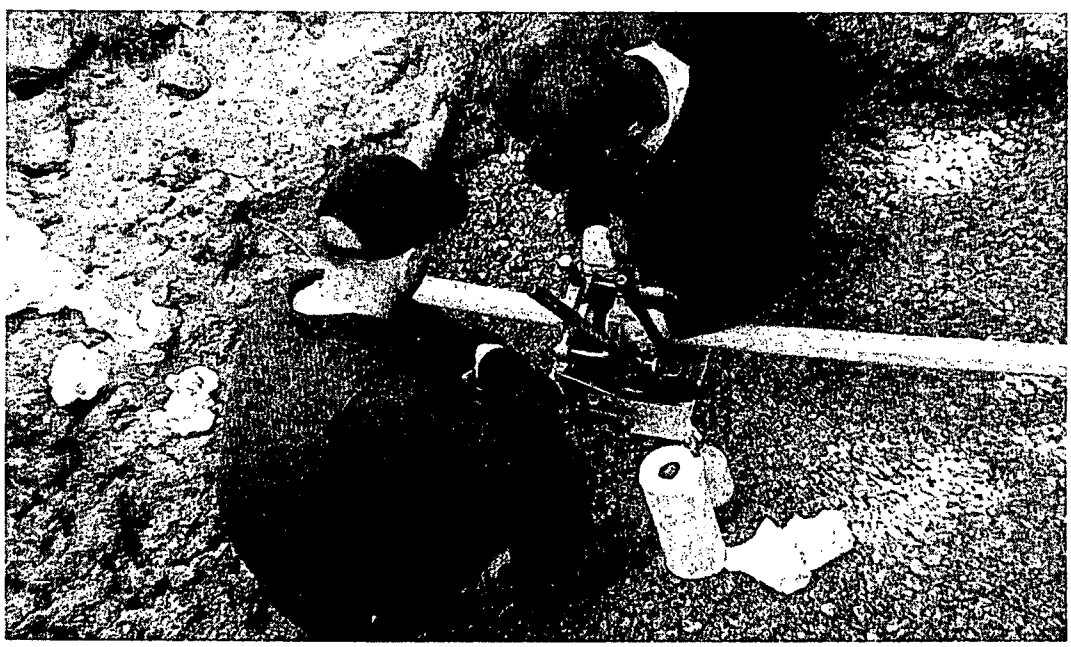
Appendix B



2" PA11 test leg when originally installed

Cutting 2" PA11 pipe for 1 year sample removal

View after sample removed



Fusing on new piece of 2" PA11 pipe to test leg