FINAL REPORT

80614001

2006 REVIEW OF DEGT HARD SPOT MANAGEMENT ACTIVITIES

Prepared For

DUKE ENERGY GAS TRANSMISSION
HOUSTON, TEXAS

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2006 REVIEW OF DEGT HARD SPOT MANAGEMENT ACTIVITIES

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EXECUTIVE SUMMARY

Duke Energy Gas Transmission (DEGT) retained CC Technologies, Inc. (CC Technologies) to review DEGT's hard spot management program. The review evaluated the hard spot program with respect to best practice. As part of the review, CC Technologies (1) critically evaluated a failure report on in-service release that was (partially) attributed to a hard spot, (2) reviewed the materials used on DEGT's system relative to historic failures in similar materials, (3) assessed the effectiveness of DEGT's in-line inspection program as it relates to hard spots, (4) evaluated DEGT's hard spot management program, and (5) prepared this report, which provides a high level summary of the results of the program.

The in-service release occurred in A. O. Smith pipe on November 2, 2003. A metallurgical failure analysis, conducted by Kiefner and Associates, Inc. (Kiefner), attributed the failure to hydrogen-induced cracking that initiated at the outer surface of the pipe in a hard spot. CC Technologies concurs with the conclusion that a hard spot was present at the failure origin and played a role in the failure.

A. O. Smith is a supplier having been cited as producing pipe with hard spots, and approximately 1,354 of the 11,500 miles in DEGT's systems were produced by A. O. Smith. CC Technologies reviewed the OPS incident database to characterize pipe associated with hard-spot failures. Some A. O. Smith pipe in DEGT's network is *not* of the vintage, diameter, wall thickness, and/or grade cited in the data.

To assess the potential impact of hard spots, DEGT prioritized pipeline segments, and planned and conducted an in-line inspection program to detect and characterize hard spots, followed by field excavations and laboratory evaluations. The in-line inspection results identified a handful of hard spots; two greater than 300 Brinell. Subsequent field excavations and laboratory evaluations showed that all hard spots were less than 300 Brinell. In addition to hardness measurements, ultrasonic wall thickness measurements and magnetic particle inspections were performed at each excavation location. No evidence of laminations or cracking was found at any of the hard spot sites. Based on the in-line inspection and the field and laboratory hardness measurements, DEGT concluded the inspection tool accurately and reliably detected and estimated the hardness levels of hard spots. CC Technologies agrees with this conclusion.

Finally and based on the assessment conducted here, CC Technologies assessed DEGT's hard spot management program relative to best practices. DEGT's program is consistent with best practice. Also, none of the results indicate a significant hard spot "problem" exists on DEGT's pipeline systems.

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INTRODUCTION

Duke Energy Gas Transmission (DEGT) retained CC Technologies, Inc. (CC Technologies) to review DEGT's hard spot management program. This program was developed in response to a service failure that occurred November 2, 2003.

This report provides a high-level summary of CC Technologies' assessment of DEGT's hard spot management program. As part of this project, CC Technologies

(1) Critically evaluated a failure report on an in-service release that was (partially) attributed to a hard spot,
(2) Reviewed the materials used on DEGT's system relative to historic failures in similar materials,
(3) Assessed the effectiveness of DEGT's in-line inspection program as it relates to hard spots,
(4) Reviewed DEGT's Hard-Spot Management Program, and
(5) Prepared this report, which provides a high level summary of the results of the program and of DEGT's hard spot management program.

BACKGROUND

DEGT initiated a hard spot management program in response to a service failure that occurred November 2, 2003, in the 30" Texas Eastern Line 15, downstream of the Danville discharge at Mile Post 501.76 (26493+05). Kiefner and Associates, Inc. (Kiefner) conducted an investigation of the failure, and in a report dated December 10, 2003, attributed the failure to an interaction between a lamination, a hard spot, embrittlement due to hydrogen, and hydrogen-related stepwise cracking[1].

After the Kiefner investigation, DEGT performed an internal assessment of its pipeline system[2,*]. This assessment was used to identify and prioritize discharge segments where hard spot were possible. These segments were then inspected using an in-line inspection (ILI) that claimed the capability of detecting and characterizing hard spots. Table 1, below, shows the results of the inspections.

Table 1. Results of In-line Inspection for Hard Spots

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[*] Appendix A contains the report on this assessment.

Job Number	OD	Section Name	# of Hard Spots Reported	Date of Survey
6584.01	30”	Owingsville Line 15	11	July 3,2004
10008.01	30”	Egypt Line 15	4	April 26, 2005
10008.02	30”	Mt. Pleasant Line 15	7	April 29, 2005
10015.01	24”	Huntsville Line 11	0	July 20, 2005

The ILI results were graded in terms of estimated hardness by the inspection vendor:

- Grade 1 = 200 to 250 Brinell.
- Grade 2 = 251 to 300 Brinell.
- Grade 3 = 301 Brinell and above.

Two of the reported hard spot indications were in the Grade 3 category (301 and 304 HB). The remaining 20 reported hard spot indications were Grade 1 or Grade 2. All excavated hard spots, including Grade 3 hard spots, were found to be not an integrity threat, and were recoated and backfilled.

Based on the in-line inspection, DEGT conducted a series of excavations, field evaluations, and laboratory studies. Field and laboratory hardness measurements were taken and compared to the reported hardness grade. DEGT concluded the inspection tool accurately and reliably detected and estimated the hardness of hard spots.

WORK SCOPE AND RESULTS

The following tasks were undertaken to meet the objectives of this project:

- Task 1. Review Metallurgical Failure Analysis of In-Service Release
- Task 2. Review Pipe Materials Used on DEGT’s Pipeline System
- Task 3. Assess the Effectiveness of DEGT’s MFL Hard-Spot ILI Program
- Task 4. Review DEGT’s Hard-Spot Management Program
- Task 5. Prepare this Final Report

Task 1. Review Metallurgical Failure Analysis of In-Service Release

Approach

In Task 1, CC Technologies reviewed the metallurgical failure analysis conducted by Kiefner and Associates (Kiefner) detailed in report “Final Report on Investigation of the Service Failure of Duke Energy’s Texas Eastern Line No. 15 – Danville Discharge at Mile Post 501.76 on November 1, 2003” dated December 10, 2003.

CC Technologies reviewed the Kiefner work plan with respect to our standard failure analysis protocols. We reviewed the fractographic and metallographic examinations, comparing them to prior failure investigations conducted by CC Technologies and publicly available failure reports by others.

We reviewed measurements of chemical composition, hardness, Charpy V-notch (CVN), yield and tensile strengths, and compared the measurements with data in our files on early generation pipe steels. We also reviewed calculations of critical flaw size.

Based on these reviews and comparisons, CC Technologies assessed Kiefner's conclusions. The assessment concentrated on the role of the hard spot and hydrogen embrittlement.

Description of DEGT Failure

On November 2, 2003, a rupture occurred on DEGT's Texas Eastern Natural Gas pipeline No. 15 at Mile Post 501.76, Station No. 26493 + 05 downstream of the Danville Compressor Station. The rupture propagated approximately 1363 feet prior to arrest. The released gas ignited and the failure origin was fire damaged. The pipeline at this location is thirty inches in diameter, with a 0.375-inch wall thickness. The pressure at the time and location of the failure was 907 psig, which corresponds to 69.8% of SMYS.

The line pipe is API 5LX Grade X52 and was manufactured by A. O. Smith Corporation using a flash welding process for the longitudinal seam weld. The pipeline was installed in 1957 and was coated with a coal tar enamel and felt wrap. Prior to commissioning, the pipeline was hydrostatically tested to a pressure of 1417 psig, which corresponds to 109% of SMYS. The pipeline was cathodically protected with an impressed current cathodic protection system. On-potentials measured at the failure location prior to failure ranged between -1200 and -1600 mV (CSE).

Summary of Failure Investigation

A 15-foot long segment of the pipe containing the origin of the rupture and plates removed from the upstream and downstream pipe joints were sent to Kiefner and Associates for analysis. The investigation consisted of visual and fractographic examination of the failed pipe, Brinnell hardness testing, chemical analysis metallography, tensile testing, and Charpy impact tests of selected pipe samples from the pipe. A scanning electron microscope (SEM) examination of the fracture surfaces was not performed because the fracture surfaces were damaged by the fire that occurred subsequent to the rupture.

Kiefner concluded that the rupture initiated as a result of hydrogen-induced cracking that initiated at the OD surface of the pipe in a hard spot that was co-existent with a mid-wall lamination. Hydrogen induced step-wise cracks also were present along the sides of the lamination. When the crack at the OD surface reached the mid-wall lamination, the combined defects were critical, resulting in an axial brittle fracture of the pipe. The hard spot was estimated to be 1 to 1 ½ inches in diameter and the lamination was estimated to be 4 ½ inches long and both are mill defects that survived the original hydrostatic test. It was speculated that atomic hydrogen produced by the cathodic protection system diffused through the pipe wall, leading to hydrogen embrittlement and hydrogen induced cracking.

Based on analysis of pipe samples that were not affected by the fire, Kiefner concluded that the pipe segment met the applicable chemical and mechanical properties in place at the time of manufacture. There was no evidence of stress corrosion cracking, significant corrosion, or pre-existing mechanical damage (such as gouges) associated with the failure.

Discussion

Much of the direct evidence, including the fracture surfaces and the microstructure of the pipe, was damaged by the fire that succeeded the failure. Characterization of the hard spot to determine a maximum hardness and size with hardness testing was not possible. As a result, the evidence for the hard spot was based on the fractography, which was compromised to some extent. The microstructure of the steel was altered by the fire and the hard spot was no longer present, as pointed out by the authors.

The co-incidence of a hard spot with a lamination seems unlikely, although not impossible. Features that are similar to the “lamination” and “step wise crack” in appearance can occur during the rupture process in highly banded microstructures. Very low hydrogen concentrations in the metal are necessary for hydrogen embrittlement of a hard spot to occur. Embrittlement would normally occur before HIC initiates.

Clearly, some defect was present at the failure location and it was not associated with time dependent flaw growth mechanisms such as corrosion and stress corrosion cracking. Time dependent flaw-growth would have been detectible, even with the fire damage that occurred. The most plausible explanation for the failure is that a hard spot was present and that it was sufficiently large to cause failure on its own. It also is likely that there was a gradient in hardness and associated toughness that cause the fractography to vary around the origin.

Table 2 is a summary of historical information from several previous hard spot failures that were experienced by gas transmission pipeline companies. As shown in the table, the majority of the failures occurred in A. O Smith line pipe having the same dimensions and vintages as that found in the recent DEGT failure. All of the hard spots were considerably larger than that which was speculated to have caused the DEGT failure. This observation supports the notion that the hard spot in the DEGT failure was larger than 1 to 1 ½ inches in diameter. It also is interesting to note that the minimum hardness of the hard spots that led to failure was 350 Brinnell, except where there were other extenuation circumstances; i.e., fire damage or SCC.

Table 2. Summary of Industry Hard Spot Failures

Pipe Manufacturer	Pipe Grade	Diameter (inches)	Wall Thickness (inches)	Coating Type	Time to Failure (Years)	Failure Stress (% SMYS)	Max Hardness, (Brinell)	Hard Spot Diameter (inches)	Comment
AOS	X52	30	0.375	Coal Tar	2.75	61.5	470	10	
AOS	X52	30	0.375	Coal Tar	9.1	64	360	8	
AOS	X52	30	0.375	Asphalt	10.75	69	477	12	
AOS	X52	30	0.375	Asphalt	19.0	70.8	267	7	Fire Damage to Pipe
YS&T	X52	20	0.25	Coal Tar	16.8	70.6	350	5 X 8	
Stelco Welland Tube	X52	24	0.25	Coal Tar	20.5	79.5	327	6 X 6	Rupture due to near neutral pH SCC
-	X52	30	0.312	Asphalt	12**	64.9	440	5 X 9	Leak due to high-pH SCC
-	X52	30	0.344	Coal Tar	19***	67.9	285	6 X 12	Rupture due to high-pH SCC, possible fire damage

Conclusions

In the original failure investigation of the November 2, 2003 DEGT failure, the authors concluded that the rupture initiated as a result of hydrogen-induced cracking that initiated at the OD surface of the pipe in a hard spot that was co-existent with a mid-wall lamination. The maximum hardness and original dimensions of the hard spot could not be measured because the resulting fire reheated and softened the original microstructure. As a result, Kiefner noted the appearance of shear lips beginning about one half inch to either side of the initiation point and, based on this observation, estimated the hard spot was about one inch in size.

CC Technologies concurs with the conclusion that a hard spot was present at the failure origin, but we believe that it was larger than one inch in diameter and that it was of sufficient size to cause the failure in the absence of any lamination. CC Technologies has observed hard spot failures that transition from brittle to ductile within the hard spot itself. In these failures, the hard spots did not end at the start of shear lips. Instead, they were much larger.

Task 2. Review Pipe Materials Used on DEGT's Pipeline System

In Task 2, CC Technologies reviewed the materials used on DEGT's pipeline systems relative to those associated with prior hard-spot incidents. CC Technologies collected data on incidents attributed to pipe-body material failures[*] from the Office of Pipeline Safety (OPS) incident database. For cases where the pipe manufacturer was identified, we assessed the frequency of pipe-body incidents relative to other pipe manufacturers. Finally, characteristics of A. O. Smith pipe in the DEGT network were compared to the OPS incident data as well information from other sources.[3].

DEGT Pipeline System Assessment

After receiving the failure investigation report, DEGT performed an internal assessment of the pipeline system to help prioritize prospective discharge segments to run an ILI tool with a claimed capability of detecting and characterizing hard spots. Reference **Error! Bookmark not defined.**, which is repeated as Appendix A, summarizes the internal assessment. A. O. Smith manufactured pipe was established as high priority in the hard spot management program. That is, the prioritization for MFL hard-spot ILI was based on information contained in an INGAA report entitled "Integrity Characteristics of Vintage Pipelines" and repeated below as Table 3.

Table 3. Industry Hard Spot Incident Summary

Pipe Seam Type	Pipe Manufacture	Pipe Production Year	Number of Incidents
Flash Weld	A. O. Smith	1952	17
		1954	1
		1955	1
		1957	1
DSAW	Bethlehem	1957	2
	Kaiser	1955	1
		1949	2
	Republic	1957	1
ERW	Youngstown Sheet and Tube (YS & T)	1947	1
		1950	1
		1960	1

DEGT's interstate transmission pipeline system consists of four operating companies with a combined mileage of approximately 11,500 miles:

- Algonquin Gas Transmission (AGT),
- East Tennessee Natural Gas (ETNG),

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[*] Incidents attributed to corrosion, third party damage, outside force, etc. were not considered.

- Texas Eastern Transmission (TETCO), and
- Maritimes and Northwest (M&N).

Of the 11,500 miles in DEGT's systems, approximately 1,354 miles are A. O. Smith line pipe[4]. Table 4 summarizes the distribution of A. O. Smith line pipe throughout the DEGT system. Appendix B provides further details on the distribution of A. O. Smith line pipe for the AGT, ETNG, and TETCO pipeline facilities[5].

Table 4. A. O. Smith Line Pipe Distribution

System	Total US Miles	Miles of A. O. Smith	% of A. O. Smith
AGT	1058	141.28	13.35
ETNG	1153	125.42	10.88
TETCO	9010	1086.92	12.06
M&N	340	0	0

The complete selection criteria considered pipe manufacture, year of pipe manufacture, nominal pipe chemistry, and geometric proximity to other failure events.**Error! Bookmark not defined.** Three sections were prioritized for ILI hard spot inspections: TETCO Line 11 Huntsville Discharge, AGT Hanover Discharge 26" Mainline and TETCO Owingsville Discharge Line 15. Ultimately, four pipeline segments were inspected with the Tuboscope MFL hard spot ILI tool (Owingsville Line 15, Egypt Line 15, Mt. Pleasant Line 15, and Huntsville Line 11).

OPS Incident Data

For comparison, CC Technologies reviewed and identified failure data reported to the OPS that *could be* attributed to hard spot defects. This section describes the approach used in the evaluation of OPS failure data in the process of identifying potential hard spot related failures.

Failure data from liquid and natural gas transmission lines, as well as, natural gas distribution lines were complied from the OPS website resulting in 37,174 individual failure incidents. This data set was reduced by removing data not potentially related to hard spots. This was accomplished by first removing all data that failed during hydrotesting. The data were further reduced by eliminating failures not associated with the pipe body. Since hard spot failures would be observed and recorded as material defects, the cause of the failure event was filtered to include only such failures. From the remaining data, failure events were removed that corresponded to butt welded, seamless, and non-steel line pipe.

The remaining 745 failure incidents represented pipe body failures that *could be* hard spot failures. The top six manufacturers that contributed to these data were identified and further investigated, as discussed below. The manufacturers are:

- A. O. Smith Company (A. O. Smith),
- Youngstown Sheet and Tube (Youngstown),
- US Steel,
- Republic Steel,
- Kaiser Steel (Kaiser) , and
- National Tube Works (National Tube).

These manufacturers combined account for roughly 150, or 20% of the possible hard spot related failures. Five hundred or 67% of the failures did not include a pipe manufacturer and were therefore excluded from the analyses. The remaining 13% were from other manufacturers.

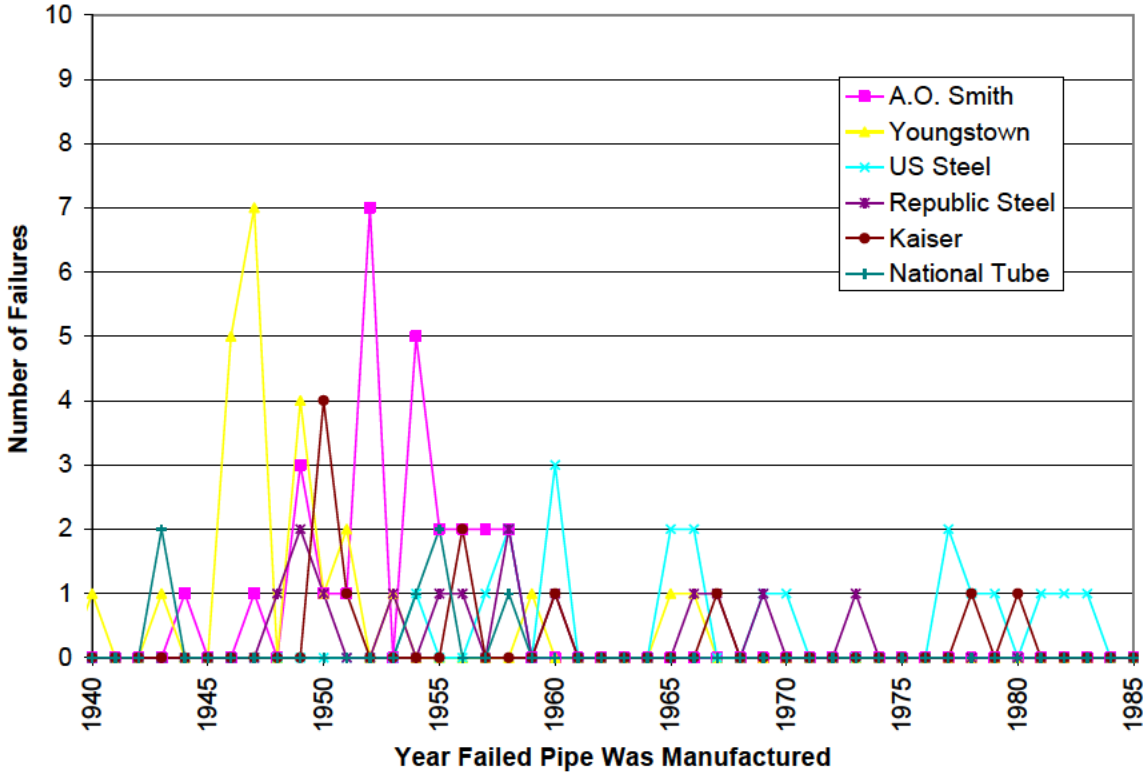

Figure 1. Number of reported failures grouped by manufacture year.

Analysis – Year of Manufacturer

Figure 1 plots the number of failures as a function of pipe manufacturer and the year in which the failed pipe was manufactured. The figure covers the period 1940 through 1985 in order to concentrate on the most common pipe production years in which a possible hard spot failure was reported. The largest number of failures occurred on line pipe that was manufactured during the 1950s.

The number of failures attributed to any one manufacturer typically shows a peak followed by a rapid decrease to (near) zero incidents per manufacturing year. That is, the companies improved either their manufacturing processes or were successful in obtaining better base materials.

Note that not all incidents reported to the OPS contain data in every field. 10% of the failures attributed to these six companies did not include the manufacture year of the failed pipe. A complete breakdown by decade of failed pipe by manufacture year can be found in Appendix C.

Analysis – Diameter, Grade, and Wall Thickness

The next attributes investigated were pipe diameter and wall thickness to assess whether there failures were more common in specific diameters and/or in heavy or light wall pipe. The resulting number of failures for pipe diameters ranging from 20 to 30 inches is illustrated in Figure 2.

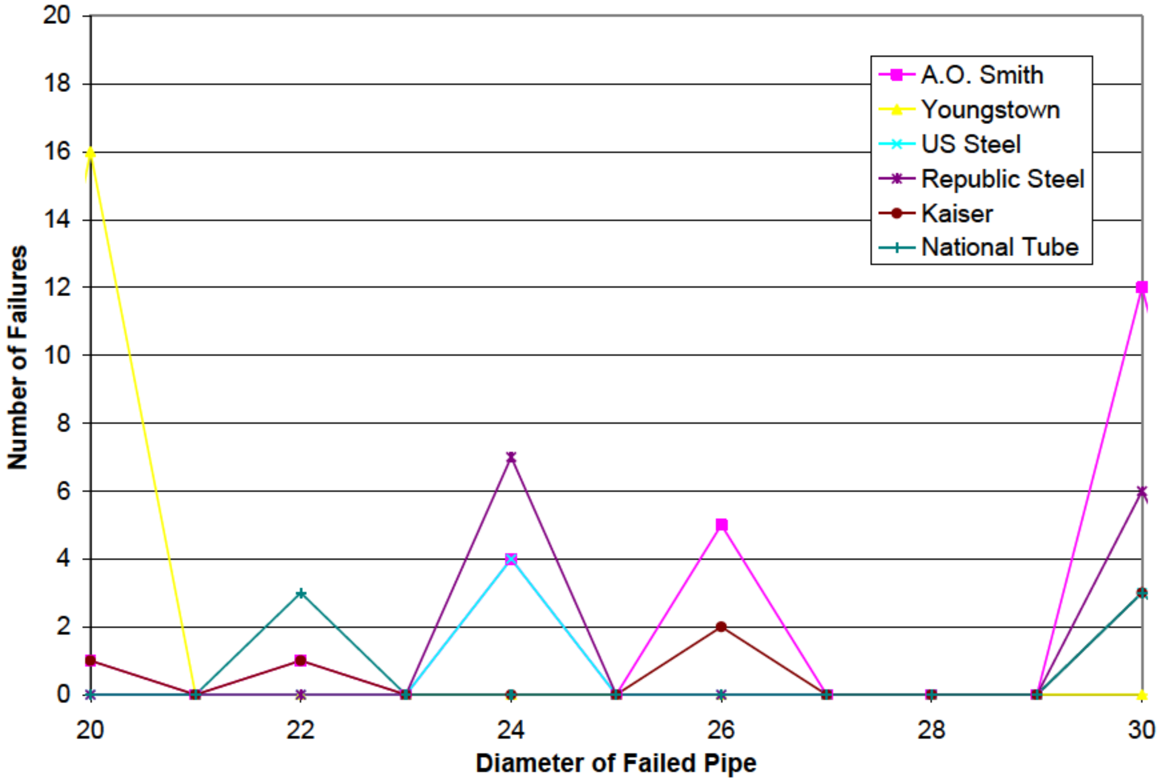

Figure 2. Number of reported failures grouped by pipe diameter.

Failed line pipe having diameters between 20 and 30 inches made up 77% of the reported data for the top six manufacturers. (Of these six manufacturers 28% of the OPS data did not include a reported diameter.) The most common diameters reported are 30 and 24 inches. A complete breakdown by pipe diameter of failed pipe can be found in the Appendix C.

The next attribute considered was pipe grade, with the number of failed pipes from the top six contributors shown in Figure 3.

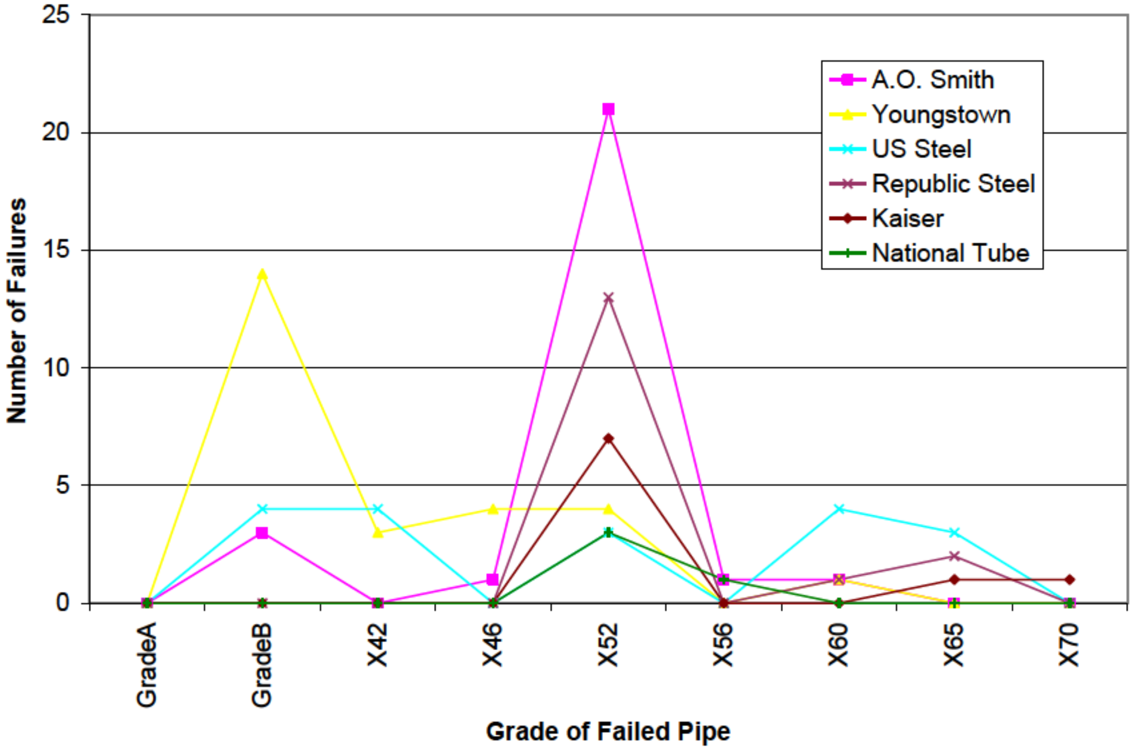

Figure 3. Number of reported failures grouped by pipe grade.

As shown in Figure 3, the most prevalent grade of failed line pipe was X52, which accounted for over 50% of all reported failures that could be attributed to hard spots. Of these, 41% were manufactured by A. O. Smith.

The final attribute investigated was wall thickness, with the results shown in Figure 4.

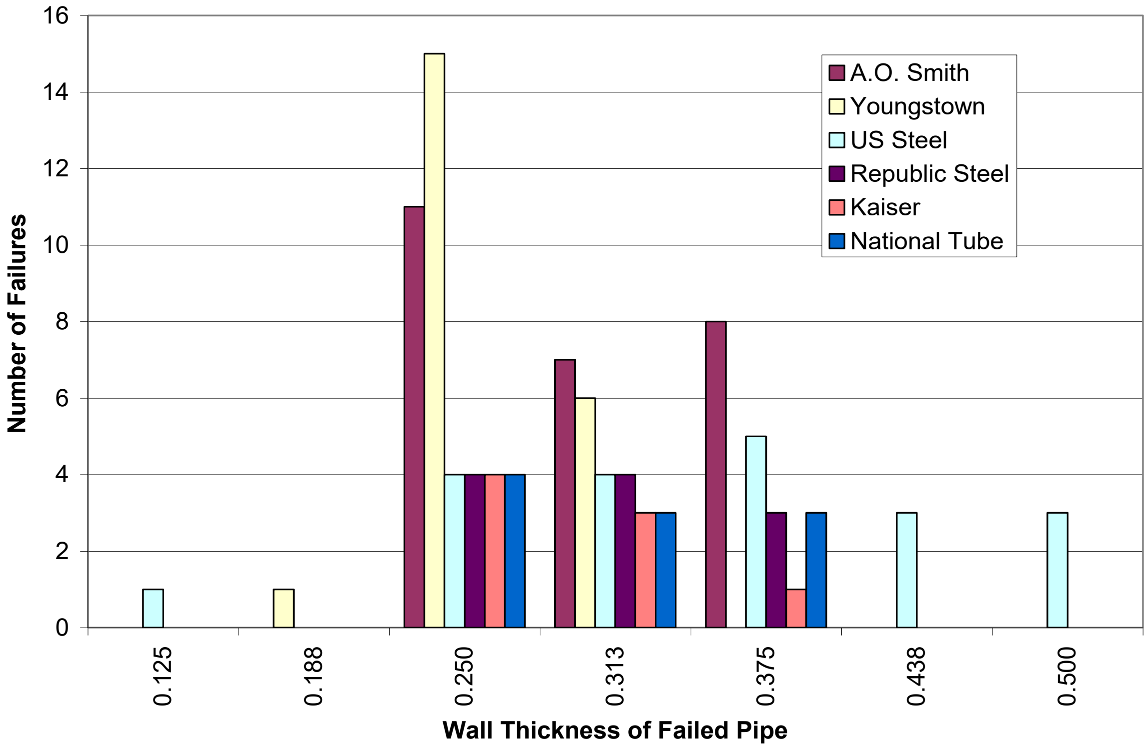

Figure 4. Number of reported failures grouped by wall thickness.

The most common wall thickness (43% of the reported data) is 0.25 inches, with Youngstown Sheet and Tube showing the highest number of failures for that wall thickness.

Results of Data Analysis

The objective of this task was to review and identify failure data reported to the OPS that could be attributed to hard spots. The specific findings are.

- Of the pipe-body incidents analyzed, most were from pipe manufactured in the 1950s. Over half of the incidents can be attributed to pipe manufactured by A. O. Smith or Youngstown Sheet and Tube.
- Over 75% of reported failures occurred on line pipe with a diameter between 20 and 30 inches. The most frequent diameters are 30 or 24 inches.
- The most common grade of pipe that failed was X52, which accounts for over half of all the reported failures.
- Of the reported failures, 43% occurred on line pipe with a wall thickness of 0.25 inches. A majority of these incidents that *could be* related to hard spots occurred on pipe manufactured by A. O. Smith and Youngstown Sheet and Tube.

A. O. Smith Pipe In DEGT's Pipeline System

As noted earlier, DEGT's interstate transmission pipeline system consists of four operating companies with a combined mileage of approximately 11,500 miles. Of the 11,500 miles in DEGT's systems, approximately 1,354 miles or 12% are A. O. Smith line pipe. *Some* of this pipe does not fall into the commonly cited categories listed above, as discussed below.

Of the 1,354 miles of A. O. Smith pipe in the DEGT system, roughly 300 miles has a diameter of 16 inches or less. CC Technologies' review uncovered no material-related pipe body incidents attributed to pipe with a diameter less than 18 inches. Other pipe can similarly be excluded as not being a grade, diameter, wall thickness, or year of manufacturer for which material-related incidents have been reported.

Task 3. Assess the Effectiveness of DEGT's MFL Hard-Spot ILI Program

In Task 3, CC Technologies reviewed MFL hard-spot ILI program and subsequent field and laboratory investigations to assess the effectiveness of the program. Appendix D includes four tables that summarize the review.

Requirements given in Owingsville Line 15 Hard Spot Assessment Plan dated June 28, 2004[6] were used as a guideline during the review. General ILI specifications established by DEGT include pipeline/survey information, ILI Service Provider personnel involved in inspection/analysis, anomaly location information, and pipe hardness to be provided in Brinell (HB) with a tolerance of ± 50 Brinell for all hard spots with a hardness ≥ 235 HB.

API 5L[7] states that any hard spot greater than 2" in any direction and a hardness greater or equal to Rockwell 35 HRC (327 Brinell) shall be rejected. The hard spot that played a role in the November, 2003, failure was reported by Kiefner to be small; 1.0" to 1.5 "in diameter.[*] Hard spots with a diameter of two inches or less may be less than the detection and reporting thresholds used by the ILI service provider.[†]

The review of the ILI analyses (reports) shows that the reports, in general, meet the criteria defined by DEGT. The following suggestions are not intended to demonstrate that the ILI analyses (reports) are not valid, but are presented for the sake of completeness and consistency.

- Similar to Owingsville Line 15, have the inspection vendor identify the MFL analyst and hard spot analyst for each inspection.
- Ask the vendor if there is a minimum planar geometric requirement for hard spot detection and characterization.
- Review prior MFL inspection of the Danville discharge section to see if any indication is evident at the location of the 2003 failure. It is possible that a hard spot with a very high Brinell measurement may be visible in the high

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[*] CC Technologies' review concluded the hard spot was larger, possibly four or five inches long.
[†] The reporting threshold is not given in the inspection reports.

magnetization field. However, reduced resolution and limited graphical display on the earlier MFL survey will make detection difficult, if at all possible.

The 24” Huntsville Line 11 was one of the top priorities identified by DEGT’s pipeline assessment, and minor operational issues and a small discrepancy were reported by the ILI vendor and/or identified in the written report. DEGT may consider a process validation be completed as described in API 1163 Section 9.1.[8] If requested by DEGT, CC Technologies can provide a guideline for the implementation of a process validation for this ILI survey.

Excavations

Ten of the eleven hard spots identified in the Owingsville section were excavated. For hard spots excavated in the Owensville section, Microdur - ultrasonic contact impedence, in addition to Telebrineller hardness tests, were used to measure hardness. Microhardness tests (using Vickers measurement) were taken at three locations(3). Two hard spots from both the Egypt and Mt. Pleasant sections were excavated(4). Telebrineller field hardness tests were performed at these locations.

Appendix E includes a graphical summary of the excavation results. For the sake of comparison, Appendix E also includes hardness values from a pipeline system that has experienced hard spot failures in the past and utilized ILI technology to detect and locate hard spot anomalies. The Brinell measurements for the historical information were made with Equotip hardness testers. It can be seen in Figure E-2 that the hardness measurements DEGT have found in their pipeline system are similar to historical hardness measurements associated with re-coats and appear much lower than the hardness measurements for hard spots that required reinforcing sleeves.

In addition to hardness measurements, ultrasonic wall thickness measurements and magnetic particle inspections were performed at each excavation location. No evidence of laminations or cracking was found at any of the hard spot sites. The results from the 14 excavated hard spots are consistent with or more conservative than the ± 50 Brinell specification given by the inspection vendor. That is, the majority of the hardness values reported by the ILI vendor met the performance specification or were higher than measured. Figure 5 plots the results in a unity graph.

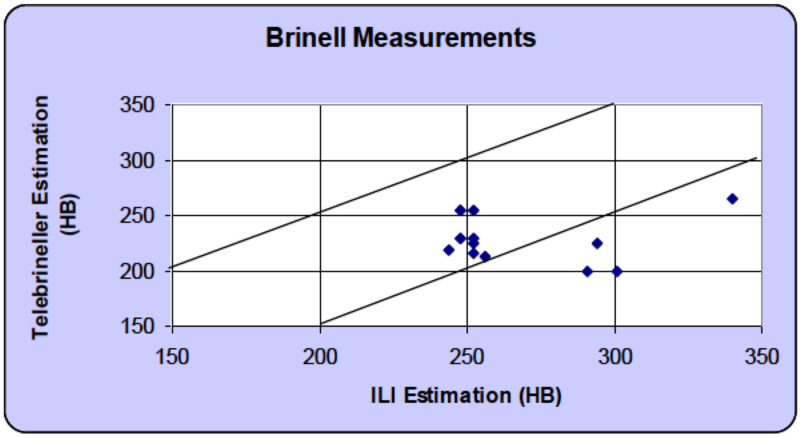


Figure 5. Unity Plot of Hardness Values.

Conclusions

Based on the in-line inspection and the field and laboratory hardness measurements, DEGT concluded that the inspection tool accurately and reliably detected and estimated the hardnesses of hard spots. After evaluating the data, CC Technologies agrees with this assessment.

The field and laboratory program also characterized the hardness levels present on DEGT's pipeline system. The measured hardness values, while elevated, were lower than that typically associated with hydrogen embrittlement and cracking of hard spots.

Task 4. DEGT Hard-Spot Management Program

In Task 4, CC Technologies used the results of Tasks 1, 2, and 3 as a backdrop against which DEGT's hard spot management program could be evaluated. The evaluation is summarized in this section. The activities evaluated are

1. An assessment of what pipe is susceptible to hard spots based on industry research.
2. A identification and ranking of susceptible pipe based on the DEGT system based on the findings from the previous activity.
3. MFL hard spot in-line inspection followed by field and laboratory testing.
4. DEGT's Threat Response Plan for manufacturing anomalies.

Assessment of Pipe Susceptibility Hard Spots

As discussed earlier, DEGT evaluated the susceptibility of line pipe to hard spots (see Reference **Error! Bookmark not defined.**, which is repeated as Appendix A). The investigation covered a number of factors, including but not limited to:

- Pipe Manufacturer
- Year of Pipe Manufacture

- Nominal Pipe Chemistry
- Geographic Proximity to Other Failure Events

The DEGT evaluation concluded:

1. The majority of incidents occurred in A. O. Smith pipe manufactured during 1952.
2. Pipe with nominally higher carbon equivalents has a lower tolerance to hydrogen absorption.
3. Proximity to known hard spot failures is important if it promotes higher atomic hydrogen solubility into a hard spot.

Role of Pipe Manufacturer and Year of Manufacture

Pipe manufacturer and year of manufacturer were discussed earlier under Task 2. Of the pipe-body incidents analyzed, most were from pipe manufactured in the 1950s and many were from 1952. The most common pipe manufacturer was A. O. Smith. These findings are consistent with DEGT's conclusions.

Role of Pipe Chemistry

The role of pipe chemistry and the mechanism of crack initiation in hard spots are not fully understood by the scientific community. Nonetheless, hard spot failures are generally associated with hardened microstructures, such as martensite and bainite. Isolated cases have been reported in ferrite-pearlite microstructures. Hardened microstructures are associated with higher carbon equivalents.

Role of Soil Components

Conditions that may promote hydrogen entry include compounds and/or species that poison the hydrogen recombination process which leads to molecular hydrogen. A relatively common poison of the hydrogen recombination reaction is the presence of sulfides.

CC Technologies understands DEGT plans to conduct an additional study on how soil chemistry affects hydrogen recombination. Plans for that study were not reviewed as part of this project.

Role of Coating and Cathodic Protection

In addition to the factors identified in DEGT's evaluation, coating condition and cathodic protection affect the potential for hydrogen embrittlement and cracking at hard spots. While an in-depth review and summary of the effects of cathodic protection on cracking in hard spots is beyond the scope of this project, some basic conclusions can be drawn.

Asphalt coated pipe tends to fail more quickly than coal tar or tape coated pipe. Hard spot failures are not common in pipe coated with fusion bond epoxy or extruded polyethylene, though, and the source of hydrogen is open to debate. Typically, studies and failure reports cite cathodic protection as the hydrogen source, but such claims are difficult to substantiate.

In a letter from CC Technologies (Kevin Garrity) to Andy Drake of Duke Energy, dated May 11, 2004,[*] CC Technologies stated that the presence of a hydrogen related problem requires the alignment of multiple factors:

1) A coating flaw is required because a steel surface must be exposed to an electrolyte for the hydrogen reaction to be possible.
2) A large amount of hydrogen reduction reaction must take place. This rate is measured by current density (i.e., mA/ft^2) and <u>not</u> directly by pipe-to-soil potential.
3) A local hard spot.
4) A location with poor hydrogen recombination reaction catalytic properties. (If all the hydrogen atoms recombine, none will enter the metal and embrittlement cannot occur.)

CC Technologies has studied the role of cathodic protection, pipe-to-soil potentials, coating damage, hydrogen charging, and cracking at hard spots. Several conclusions were reached.

First, there is no demonstrated role of cathodic protection in hard spot cracking. Other reactions, such as hydrogen charging due to corrosion in the absence of effective cathodic protection, could be significant. That is, hydrogen evolution could be the results of *inadequate* cathodic protection rather than overprotection.

Second, the pH at the pipe-to-soil interface increases when cathodic protection is applied. This causes the potential needed to evolve hydrogen to decrease (become more negative), which reduces the likelihood of embrittlement. The potential must be very low, below -1.12 to -1.15 V, for hydrogen to evolve at a significant rate. Local potentials below -1.12 to -1.15 V are uncommon.

Third, close-interval survey and other measurements made on the DEGT system showed no correlation between pipe-to-soil potentials and coating damage. While this does not rule out the possibility of some hydrogen evolution, it suggests the cathodic protection levels were not excessive.

In summary, the effects of cathodic protection on hydrogen evolution are complex, and there is no simple method of monitoring or controlling pipe-to-soil potentials to reduce or eliminate the likelihood of embrittlement or cracking. Hard spot failures are infrequent, and the risk of failure due to external corrosion is much larger than the risk of hydrogen-related cracking. So, priority should be given to maintaining adequate cathodic protection.

---

[*] This letter is included as Appendix F to this report.

Identification and Ranking of Susceptible Pipe on the DEGT System

In the assessment discussed above, DEGT identified and prioritized three lines for MFL hard spot in-line inspection:

1) TETCO Line 11, Huntsville Discharge
2) AGT Hanover 26” M/L Discharge
3) TETCO Owingsville Line 15 Discharge

As discussed in the next section, DEGT conducted an MFL hard spot in-line inspection on the two TETCO lines identified above and on TETCO Mount Pleasant Line 15 Discharge and TETCO Egypt Line 15 Discharge.

Table 4, shown earlier and repeated below, summarizes the distribution of A. O. Smith pipe on DEGT’s pipeline systems. TETCO Line 11 Huntsville Discharge contains ~32 miles of A. O. Smith pipe manufactured in 1952. The TETCO Owingsville Line 15 Discharge contains ~25 miles, the Mount Pleasant Discharge section 54 miles, and the Egypt Discharges section 60 miles, all of which were manufacturer in or around 1956-7. These segments would be considered to have an elevated susceptibility to hard-spots based on the results of this study.

The AGT Hanover 26 inch Discharge segment is scheduled for inspection in 2006/7. It contains ~31 miles of A. O. Smith pipe produced in 1952. This segment would have been considered to have an elevated susceptibility to hard sports.

Table 4. A. O. Smith Line Pipe Distribution

System	Total US Miles	Miles of A. O. Smith	% of A. O. Smith
AGT	1058	141.28	13.35
ETNG	1153	125.42	10.88
TETCO	9010	1086.92	12.06
M&N	340	0	0

MFL Hard Spot In-Line Inspection Followed By Field And Laboratory Testing

As discussed above, DEGT conducted MFL hard spot in-line inspections on four line segments. Table 1, shown earlier and repeated below, summarizes the results. A detailed discussion of the results of the MFL program, as well as the field and laboratory measurements, is given under Task 3 and summarized in Appendix D.

Table 1. Results of In-line Inspection for Hard Spots

Job Number	OD	Section Name	# of Hard Spots Reported	Date of Survey
6584.01	30”	Owingsville Line 15	11	July 3,2004
10008.01	30”	Egypt Line 15	4	April 26, 2005
10008.02	30”	Mt. Pleasant Line 15	7	April 29, 2005
10015.01	24”	Huntsville Line 11	0	July 20, 2005

A series of of field and laboratory evaluations were conducted following the MFL hard spot inspection. The results are discussed under Task 3 and summarized in Appendix E. Based on these evaluations and comparisons with the in-line inspection data, DEGT concluded the inspection tool accurately and reliably detected and estimated the hardness levels of hard spots. CC Technologies agrees with this conclusion.

Based on an early study of industry field failures in hardened regions, hardness values greater than 361 Brinell (about 39 Rockwell C) were necessary for cracking to initiate. Common industry guidelines suggest hardness below 327 Brinell (35 Rockwell C) provide protection against hydrogen related cracking.

The Brinell hardness values reported as a result of the in-line inspection are all below 300 Brinell. Similarly, the hardness values measured by DEGT in the field and laboratory are similarly all below 300 Brinell. The highest reported value was 255 Brinell.[9,10] These hardness values are well below those cited above, which suggests these pipe are not likely to fail by hydrogen embrittlement.

DEGT’s Threat Response Guidance Document

DEGT’s Threat Response Guidance (TRG) for manufacturing anomalies includes hydrogen-cracking in hard spots. The TRG calls for data collection, integration, and assessment based on input from Subject Matter Experts (SMEs).

DEGT’s TRG for manufacturing defects begins with a screening process. Lines that are constructed of pipe manufactured to 1969 standards (or later) are excluded, as are segments where there are no “material related concerns in the opinion of the SME." While specific guidelines for the SMEs are not given in the TRG, presumably information and guidelines established here or in prior work are used.

For line segments that have not been excluded per the previous paragraph, a more detailed assessment is performed. As part of this assessment, information related to pipe manufacturer and industry history is considered. In addition, the presence of hard spots as identified in an ILI is considered. If hard spots have been identified by an ILI and not remediated and/or if in ILI for hard spots has not been performed, SMEs evaluate the potential threat by reviewing operational data, coating condition, cathodic protection data, and environmental data. Again, specific guidelines for the SMEs are not given.

Where DEGT's TRG provides general guidelines, the implementation is best assessed as discussed earlier on the basis of specific actions and responses. DEGT implemented its TRG by identifying A. O. Smith pipe that may be more susceptible to hard spots. DEGT then conducted an in-line inspection of five pipeline segments, after which it conducted both field and laboratory evaluations.

The field and laboratory program characterized the hardness levels present on DEGT's pipeline system. The measured hardness values, while elevated, were lower than that typically associated with hydrogen embrittlement and cracking of hard spots.

Summary

DEGT's hard spot management program includes a number of activities including but not limited to:

1. An assessment of what pipe is susceptible to hard spots based on industry research.
2. A identification and ranking of susceptible pipe based on the DEGT system.
3. MFL hard spot in-line inspections followed by field and laboratory testing.
4. DEGT's Threat Response Plan for hard spots.

CC Technologies' assessment of the program shows its basis and application to be consistent with industry best practices.

CONCLUSIONS

Subsequent to a service failure in November, 2003, DEGT Gas Transmission implemented a hard spot management program. The primary focus of this program is to identify susceptible pipeline segments, prioritize these locations with respect to risk severity, perform an in-line inspection, and excavate hard spot areas which have the potential for hydrogen induced cracking. Based on the assessment, CC Technologies concluded DEGT's hard spot management program is consistent with best practices. Based on the results evaluated here, no evidence was found to indicate a significant hard spot "problem" exists on DEGT's pipeline systems.

There is strong evidence that the pipe manufacturer most frequently associated with hard spot failures is A. O. Smith. Most A. O. Smith hard-spot incidents are attributed to pipe made between 1952 and 1958. DEGT identified and assessed A. O. Smith pipe from this vintage, finding no evidence of a significant hard-sport "problems."

DEGT plans to continue using MFL hard spot in-line inspection tools on a base-by-case basis in what may be considered susceptible materials. Based on the results of this project, CC Technologies agrees with this approach.

REFERENCES

1. Raymond E. Mesloh and M. J. Rosenfeld, P. E., "Final Report on Investigation of the Service Failure of Duke Energy's Texas Eastern Line No. 15 – Danville Discharge at Mile Post 501.76 on November 1, 2003", Kiefner and Associates, Inc., December 10, 2003.

2. Memorandum – Selection Criteria for Hardspot ILI Examination, memo from Steve Rapp to Andy Drake, January 27, 2004.

3. Integrity Characteristics of Vintage Pipelines, E.B. Clark, et al, October 2004.

4. Duke Energy Gas Transmission A. O. Smith Impact Map, 2004.

5. Duke A. O. Smith Spreadsheets (electronic): AGT (November 10, 2003), TETCO (November 11, 2003), ETNG (November 10, 2003).

6. Owingsville Line 15 Hard Spot Assessment Plan, June 28, 2004.

7. API 5L, "Specification for Line Pipe", 41st Ed., April 1, 1995.

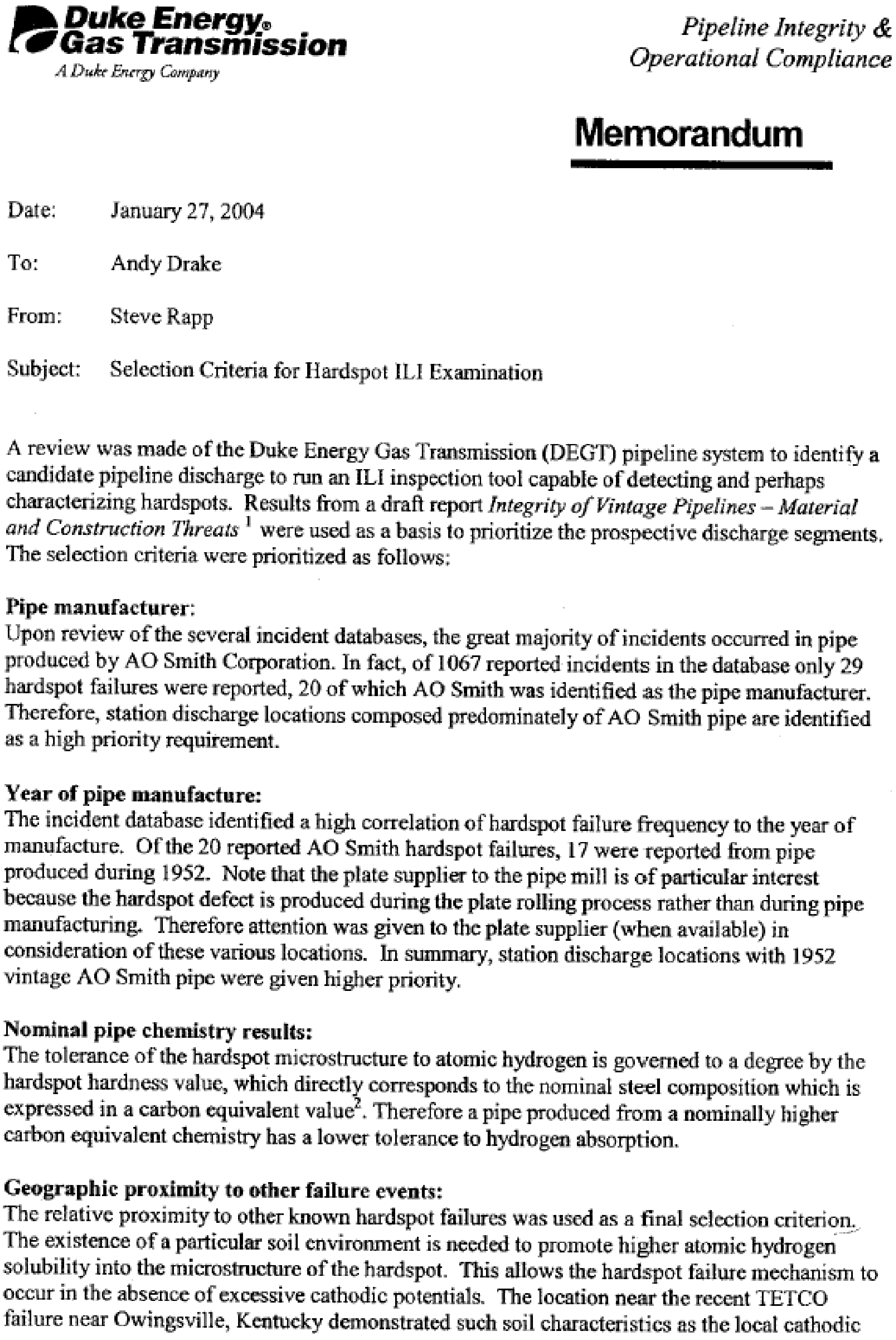
8. API 1163, "In-line Inspection Systems Qualification Standard". 1st Ed., August 1, 2005.

9. Metallurgical Assesment [sic] of Owingsville Line 15 for Hard Spots, G. Vervake, November 10, 2004.

10. Metallurgical Assessment of Egypt and Mt. Pleasant Line 15 for Hard Spots, G. Vervake, March 9, 2006.

APPENDIX A.

Selection Criteria for Hard Spot ILI Examinations



Duke Energy® Gas Transmission
A Duke Energy Company

Pipeline Integrity &
Operational Compliance

Memorandum

Date: January 27, 2004

To: Andy Drake

From: Steve Rapp

Subject: Selection Criteria for Hardspot ILI Examination

A review was made of the Duke Energy Gas Transmission (DEGT) pipeline system to identify a candidate pipeline discharge to run an ILI inspection tool capable of detecting and perhaps characterizing hardspots. Results from a draft report *Integrity of Vintage Pipelines – Material and Construction Threats* [1] were used as a basis to prioritize the prospective discharge segments. The selection criteria were prioritized as follows:

Pipe manufacturer:
Upon review of the several incident databases, the great majority of incidents occurred in pipe produced by AO Smith Corporation. In fact, of 1067 reported incidents in the database only 29 hardspot failures were reported, 20 of which AO Smith was identified as the pipe manufacturer. Therefore, station discharge locations composed predominately of AO Smith pipe are identified as a high priority requirement.

Year of pipe manufacture:
The incident database identified a high correlation of hardspot failure frequency to the year of manufacture. Of the 20 reported AO Smith hardspot failures, 17 were reported from pipe produced during 1952. Note that the plate supplier to the pipe mill is of particular interest because the hardspot defect is produced during the plate rolling process rather than during pipe manufacturing. Therefore attention was given to the plate supplier (when available) in consideration of these various locations. In summary, station discharge locations with 1952 vintage AO Smith pipe were given higher priority.

Nominal pipe chemistry results:
The tolerance of the hardspot microstructure to atomic hydrogen is governed to a degree by the hardspot hardness value, which directly corresponds to the nominal steel composition which is expressed in a carbon equivalent value[2]. Therefore a pipe produced from a nominally higher carbon equivalent chemistry has a lower tolerance to hydrogen absorption.

Geographic proximity to other failure events:
The relative proximity to other known hardspot failures was used as a final selection criterion. The existence of a particular soil environment is needed to promote higher atomic hydrogen solubility into the microstructure of the hardspot. This allows the hardspot failure mechanism to occur in the absence of excessive cathodic potentials. The location near the recent TETCO failure near Owingsville, Kentucky demonstrated such soil characteristics as the local cathodic

protection levels were found to be normal (not excessive). Also, reports of several failures in the mid-Texas and northeast Louisiana region demonstrate conducive soil environments for hardspot failures.

Conclusions:
Using the prioritized conditions above matched against the attributes of the DEGT transmission system, three locations for ILI inspection are provided below (in order of priority):

TETCO Line 11 – Huntsville Discharge
The discharge contains 31.93 miles of AO Smith pipe produced in 1952. The pipe documentation indicates two plate suppliers were used for the 24" diameter pipe purchase (USS Homestead works and USS South Chicago works). The discharge location is just north of Houston where conducive soil chemistry is expected. The discharge operates at a nominal stress level of 75% SMYS. The nominal pipe chemistry has an average CE value of 0.43.

AGT Hanover 26" M/L Discharge
The Hanover discharge contains 30.84 miles of AO Smith pipe produced in 1952. The pipe documentation does not indicate the plate supplier to the pipe mills. The location is not in an area expected to be conducive for atomic hydrogen evolution and the pipeline operates at a lower nominal stress level. The Hanover discharge operates at a nominally low operating stress of 45% SMYS. The nominal chemistry for the location has an average CE of 0.44. The lower nominal operating stress drops this location into a clear second choice.

TETCO Owingsville Line 15 Discharge
The Owingsville discharge contains 24.76 miles of AO Smith pipe produced in 1957. Although the 1957 vintage is of no particular interest, the location of Owingsville Station has demonstrated a conducive soil chemistry as evidenced by the recent upstream failure in November 2003. The nominal pipe chemistry from this pipe purchase has an average CE of 0.41. The Owingsville discharge has the collateral benefit that it contains several DOT waiver sites which operate at a grandfathered stress value of 77% SMYS. While the pipe attributes for the Owingsville discharge do not match well against the prioritized criteria, Owingsville earns some consideration for the reasons given above.

Note that in the event that a hardspot ILI is conducted, additional work is required to develop field assessment, acceptance criteria, and repair methodology for any anomaly indications.

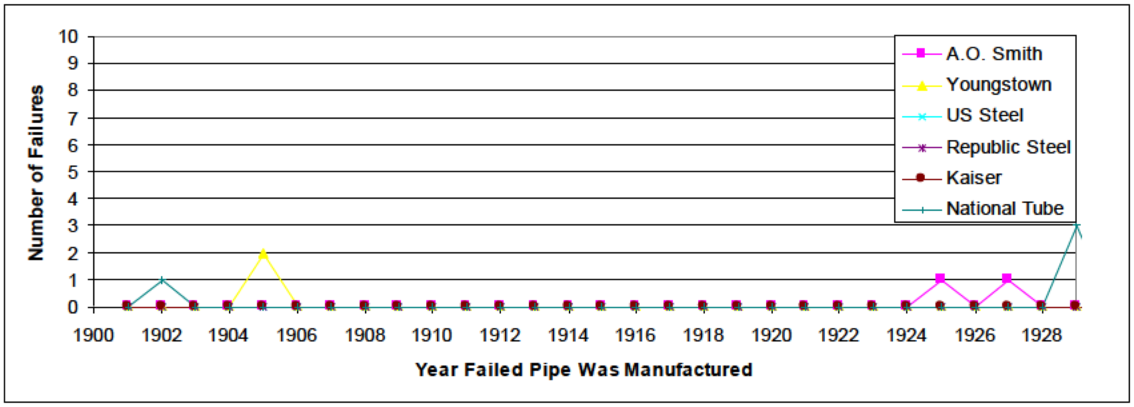
If there are any questions, please advise.

1. Draft Report on Integrity of Vintage Pipelines – Material and Construction Threats, prepared To the Interstate Natural Gas Association of America (INGAA) and The American Gas Association (AGA), Battelle, July 24, 2003

2. Carbon Equivalent (CE_{IIW}) = $C + Mn/6 + (Cr+Mo+V)/5 + (Cu+Ni)/15$

APPENDIX C.

Historic Data Related To Pipe Body Failures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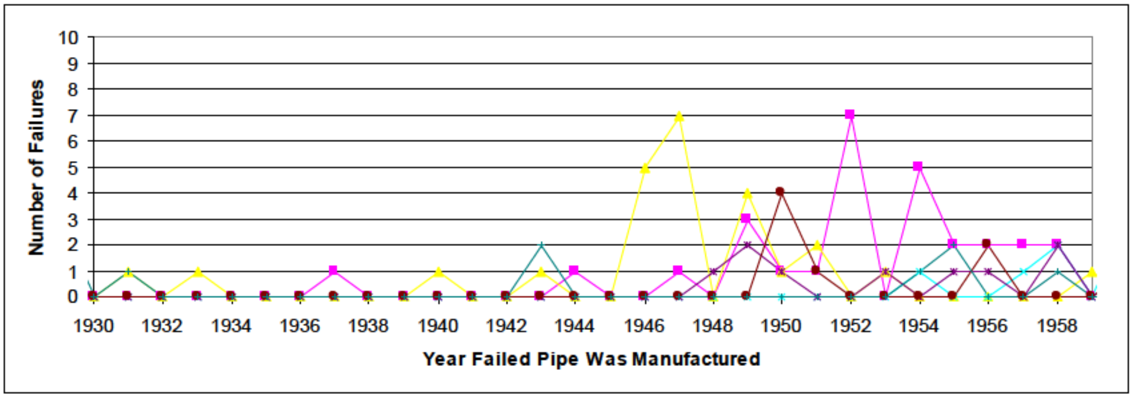
9
8
7
6
5
4
3
2
1
0
1900
1902
1904
1906
1908
1910
1912
1914
1916
1918
1920
1922
1924
1926
1928
Year Failed Pipe Was Manufactured
A.O. Smith
Youngstown
US Steel
Republic Steel
Kaiser
National Tube


Number of Failures
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9
8
7
6
5
4
3
2
1
0
1930
1932
1934
1936
1938
1940
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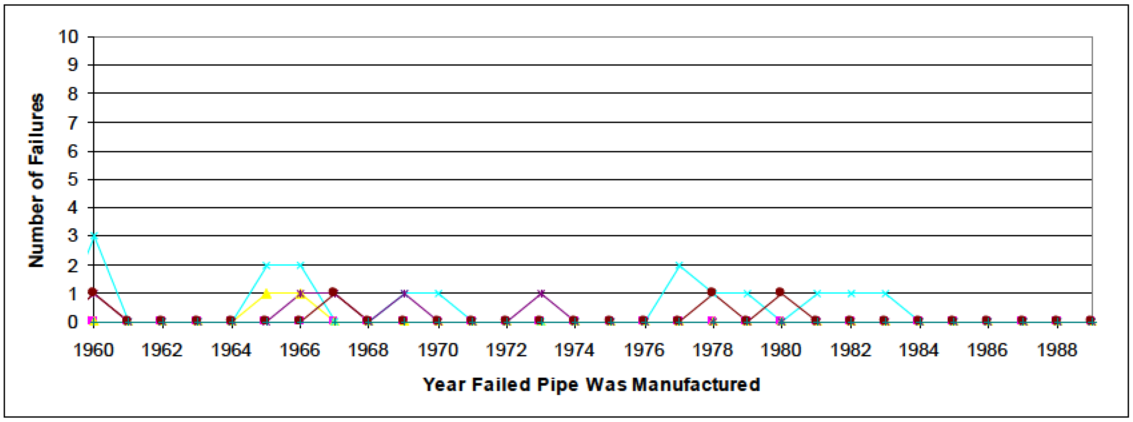
1944
1946
1948
1950
1952
1954
1956
1958
Year Failed Pipe Was Manufactured


Number of Failures
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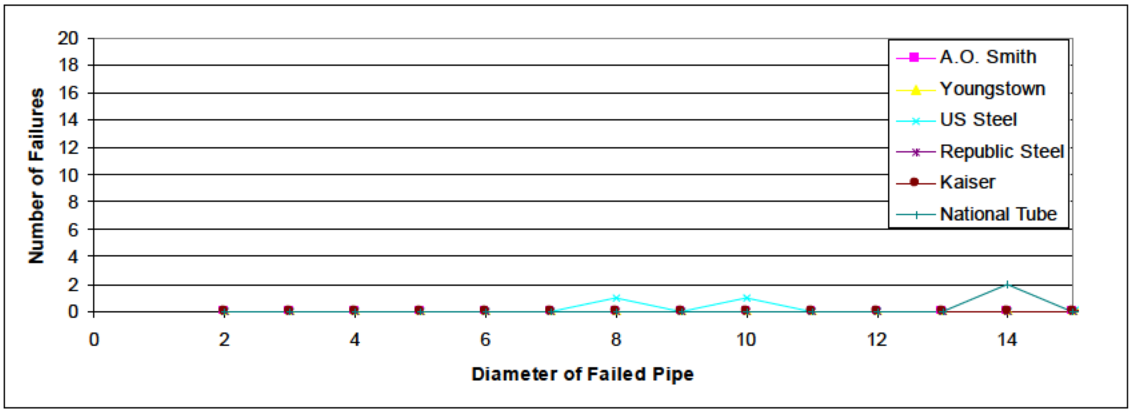
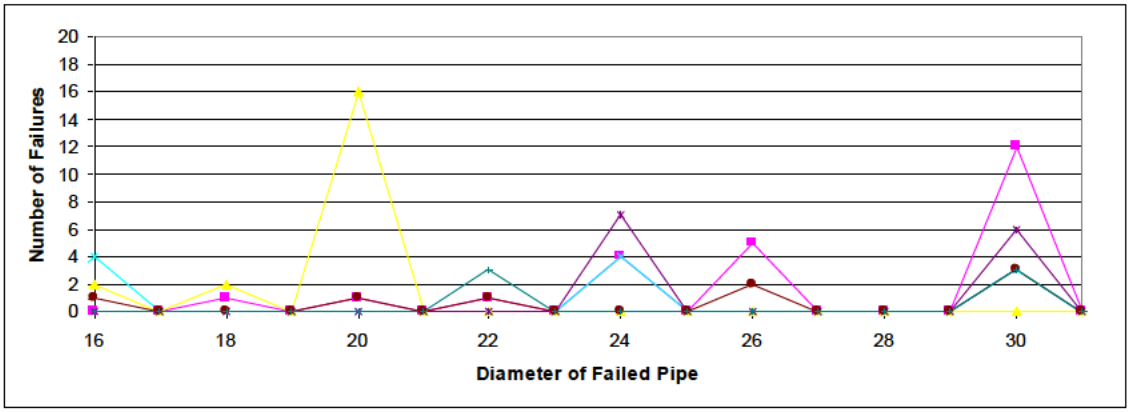
8
7
6
5
4
3
2
1
0
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
Year Failed Pipe Was Manufactured


Number of Failures
0
2
4
6
8
10
12
14
16
18
20
0
2
4
6
8
10
12
14
Diameter of Failed Pipe
A.O. Smith
Youngstown
US Steel
Republic Steel
Kaiser
National Tube


Number of Failures
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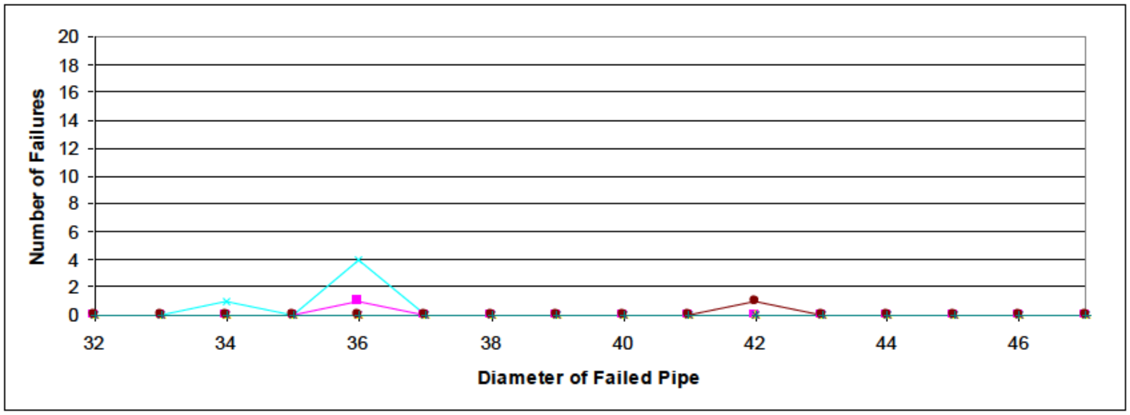
2
4
6
8
10
12
14
16
18
20
16
18
20
22
24
26
28
30
Diameter of Failed Pipe


Number of Failures
0
2
4
6
8
10
12
14
16
18
20
32
34
36
38
40
42
44
46
Diameter of Failed Pipe

APPENDIX D.

Review ILI Analyses (Reports)

D-1. Pipeline segments with ILI hard spot surveys.

Job Number	OD	Section Name	# of Hard Spots Reported	Date of Survey
6584.01	30”	Owingsville Line 15	11	July 3,2004
10008.01	30”	Egypt Line 15	4	April 26, 2005
10008.02	30”	Mt. Pleasant Line 15	7	April 29, 2005
10015.01	24”	Huntsville Line 11	0	July 20, 2005

Table D-2. ILI survey requirements.

Survey / Info	Owingsville Line 15	Egypt Line 15	Mt. Pleasant Line 15	Huntsville Line 11
• Section	√	√	√	√
• Line Size/Num	√	√	√	√
• Survey Date	√	√	√	√
• Tuboscope #	√	√	√	√
• Run #	2	1	1	2
• Inspector	√	missing page	√	√
• Analyst	√ (MFL and hard spot)	missing page	√ (only one analyst noted)	√ (only one analyst noted)

Table D-3. Logistics and data quality.

Logistics/ Problems \ Survey	Owingsville Line 15	Egypt Line 15	Mt. Pleasant Line 15	Huntsville Line 11
Launch Date/Time	Jul 3, 2004 7:37 am	Apr 26, 2005 7:20 am	Apr 29, 2005 6:51 am	Jul 20, 2005 8:26 am
Trap Date/Time	Jul 3, 2004 6:08 pm	Apr 26, 2005 9:14 pm	Apr 29, 2005 6:35 pm	Jul 20, 2005 7:40 pm
Line Length	62.18 miles	71.26 miles	63.52 miles	61.09 miles
Tool in Line	10 hours 31 minutes	13 hours 54 minutes	11 hours 16 minutes	11 hours 14 minutes
Aver. Speed	5.91 mph	5.13 mph	5.45 mph	5.4 mph
MFL Channel Quality	√	MFL sensor #110 intermittent throughout survey	MLF sensors #110 and #62 intermittent at 500' and 66,667' respectively	√
Hard spot Channel Quality	√	√	Hard spot sensor #4 became inoperable at launch	Hard spot channels #25, 26, and 27 became intermittent at the launch
Modified Report	Yes – Marker locations added	Yes – Due to receipt of more recent caliper survey information	No	No
Other Comments	None	None	None	AGMs 1,3,9,13 could not be matched with stat. #s. The tool speed was occasionally outside of it's primary range of effectiveness

APPENDIX E.

Summary of Excavation Results

Table E-1. Reported hard spots in ILI survey.

Section Name	# of Hard spots	200-300 Brinell	301 Brinell and Greater	Other Possible
Owingsville Line 15	11	11	0	?
Egypt Line 15	4	4	0	0
Mt. Pleasant Line 15	7	5	2	0
Huntsville Line 11	0	0	0	0

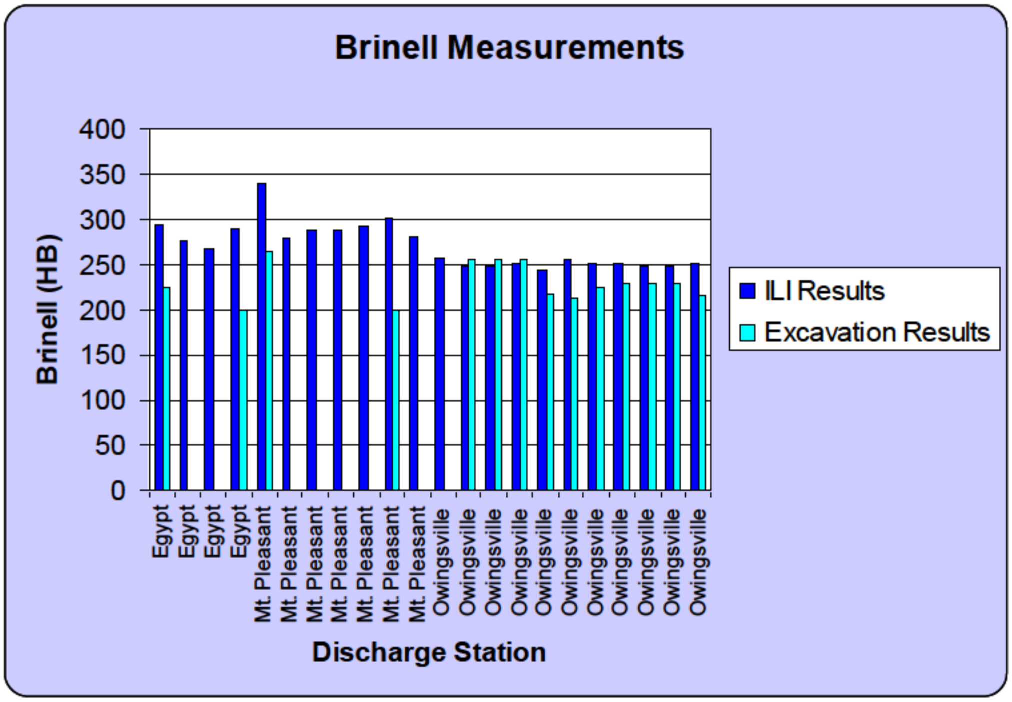


Figure E-1. Brinell Measurements from ILI and Excavations.

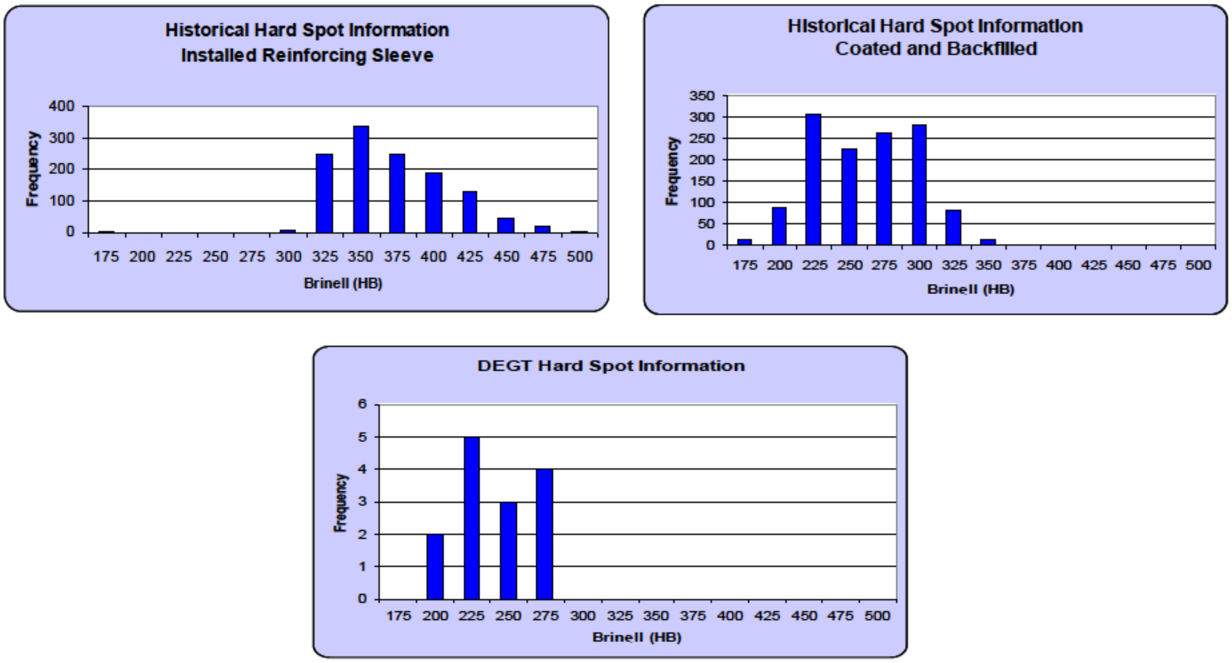


Figure E-2. Historical hard spot measures compared to Duke Energy's hard spot measures.

APPENDIX F.

Letter from CC Technologies (Kevin Garrity) to Andy Drake of Duke Energy, dated May 11, 2004.

CC Technologies
SOLVING PROBLEMS THROUGH INNOVATION

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Senior Engineer

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Senior Project Manager

May 11, 2004

J. A. Drake, P.E.
Director, Pipeline and Operational Compliance
Duke Energy
5400 Westheimer
Houston, TX 77056

Re: CP Effects at Hard Spots

Mr. Drake:

I am Chairman of NACE Task Group TG 285 which is tasked with reviewing and recommending changes to the criteria section in RP0169 on Cathodic Protection of Buried Pipelines. The Task Group has been considering and studying the role of hydrogen in coating damage and embrittlement of susceptible pipelines (higher strength steels), however the Task Group has not come to agreement on the need and benefit for introducing an upper potential limit to reduce the already infrequent number of cases where cathodic protection has been found to be harmful. The Task Group has instead focused on the need to quantify the minimum levels of cathodic protection necessary to mitigate the far more common external corrosion integrity threats posed by MIC, SCC and general and localized corrosion in aggressive soil environments where it is known that more conservative thresholds are needed.

The most recent communication from OPS points out the industry-wide problem of having to provide enough cathodic protection to mitigate the more aggressive mechanisms that have lead to many corrosion problems while trying to prevent the very rare occurrence of hydrogen induced damage.
Consideration of the comments from OPS letter does not change the overall conclusion of the CC Technologies analysis. In summary, the presence of a hydrogen related problem requires the alignment of at least 3 and possibly 4 factors:

1) Coating Flaw - A coating flaw is required because a steel surface must be exposed to an electrolyte for the hydrogen reaction to be possible.

2) High CP – A large amount of hydrogen reduction reaction must take place. This rate is measured by current density (i.e., mA/ft^2) and not directly by pipe-to-soil potential. It should be considered that oxygen is also reduced, so the measured current is the sum of both reactions (and only the hydrogen reaction can input hydrogen to the metal). The difference between polarized potential and reversible potential represents the driving force for the reactions.

3) Local Hard Spot – Typical pipeline steels are not considered susceptible to hydrogen related cracking unless a local difference in material properties exists.

4) Location with poor hydrogen recombination reaction catalytic properties. When hydrogen is reduced, the neutral hydrogen atom is adsorbed on the steel surface. If all the hydrogen atoms recombine, none will enter the metal and embrittlement cannot occur. However, some surfaces have poor catalytic properties for hydrogen recombination allowing the hydrogen to remain adsorbed on the surface (i.e., the concentration on the surface is greater) resulting in more H in the metal. A particularly strong recombination reaction poison is iron sulfide (which is the basis for Sulfide Stress Cracking), and one source of iron sulfide on pipelines is from sulfate reducing bacteria (SRB). It has therefore been theorized that hydrogen embrittlement is unlikely unless microbiological activity is present.

In the memorandum from OPS three questions are raised:

1. Accuracy of the Nernst Equation

The use of the simplified Nernst equation was intended to illustrate the concept that alkaline environments, as typically found on cathodically protected pipelines, result in more negative reversible (i.e., equilibrium potentials) of the hydrogen reduction reaction. The rate of hydrogen evolution is proportional to the driving force of the reaction and the driving force is defined as the difference between the polarized (i.e., instant-off) potential and the reversible potential. Because of this, the rate of hydrogen reduction is expected to be reduced in the alkaline environment as compared to the same polarized potential in a neutral environment.

The relationship between current and the potential driving force for kinetically controlled reactions is roughly 100mV/decade. That is, polarizing by 100mV typically results in a 10-fold increase in current. It should be noted that the current also depends on the 'exchange current density' at the reversible potential. The current density at a particular potential is therefore difficult to predict with accuracy. Regardless, the shift to alkaline pH results in a hydrogen reduction current several orders of magnitude less than at a neutral pH.

The simplified Nernst equation showed that at standard conditions and pH of 12, the reversible potential is -1025mV (Cu/$CuSO_4$). As shown by Mr. Mataich, reducing the temperature to 40F (the pipeline operates at 55F), changes the reversible potential by 50mV (to -975mV). It should be considered that, in general, the effect of temperature on the kinetics of reactions is that a 10C increase in temperature doubles the reaction rate. A decrease in temperature therefore simultaneously increases the driving force for reaction but decreases the rate constant for reaction (i.e., the effects are opposing). A further assumption with respect to using the Nernst equation is the hydrogen gas pressure.

2. Pipe-to-soil potentials exceeding the reversible potential

It is believed that pipe-to-soil potential exceeds the reversible potential because the rectifier is applying cathodic current. In fact, this current creates the alkaline environment resulting in reduced current demand (i.e., lower hydrogen reduction rate). However, the change in reversible potential supports the argument that this current is not excessive. It should also be considered that part of the current is associated with oxygen reduction (which does not generate hydrogen). Without knowing the rate of oxygen transport to the steel surface, the portion of oxygen reduction in the total cathodic current cannot be determined.

It should be noted that the close interval survey (CIS) data serve as the polarized potential on the pipeline, and the continuous logs are not considered accurate with respect to the polarized potential. The continuous log is intended to monitor possible stray current activity and ensure proper synchronization of rectifier interruption. The reference electrode is distant from the pipe and possibly affected by IR-drop errors. Regardless, the CIS data near the rectifier shows potentials more negative than the reversible potentials.

3. Excessive hydrogen evolution

CC Technologies agrees with Mr. Mataich in that the data support the premise that hydrogen evolution occurs when a pipeline is under cathodic protection, but the shift of the hydrogen reversible potential (as illustrated by use of the Nernst equation) supports the conclusion that the rate of evolution is not excessive. The use of the Nernst equation successfully demonstrates that cathodic protection potentials maintained on the Duke pipeline are not excessively negative and not generating excessive levels of hydrogen.

In summary, while OPS makes valid comments on the use of the Nernst equation, they do not change the overall conclusion that the level of cathodic polarization cannot be considered excessive on the basis of available data.

Very truly yours,
CC Technologies Services, Inc.

[redacted]

Kevin C. Garrity, P.E.
COO