

Internal Repair of Pipelines Semi-Annual Technical Progress Report

Reporting Period:
September 30, 2002 through March 31, 2003

Principal Authors:
Robin Gordon, Bill Bruce, Nancy Porter, Mike Sullivan, and Chris Neary

Report Issued: May 2003
Revised: June 24, 2003
Revision #1

DOE Award No.: DE-FC26-02NT41633

Submitted By:
Edison Welding Institute
1250 Arthur E. Adams Drive
Columbus, OH 43221

Significant Subcontractor:
Pacific Gas & Electric
3400 Crow Canyon Road
San Ramon, CA 94583

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed or represents that its use would not infringe privately owned rights. Reference herein to otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency hereof.

Measurement Units -- SI Metric System of Units are the primary units of measure for this report followed by their U.S. Customary Equivalents in parentheses ().

Note: SI is an abbreviation for "Le Systeme International d'Unites."

ABSTRACT

The two broad categories of deposited weld metal repair and fiber-reinforced composite repair technologies were reviewed for potential application for internal repair of gas transmission pipelines. Both are used to some extent for other applications and could be further developed for internal, local, structural repair of gas transmission pipelines.

Preliminary test programs were developed for both deposited weld metal repairs and for fiber-reinforced composite repair. To date, all of the experimental work pertaining to the evaluation of potential repair methods has focused on fiber-reinforced composite repairs. Hydrostatic testing was also conducted on four pipeline sections with simulated corrosion damage: two with composite liners and two without.

TABLE OF CONTENTS

	<u>Page</u>
DISCLAIMER	ii
ABSTRACT	iii
TABLE OF CONTENTS	iv
LIST OF GRAPHICAL MATERIALS	v
1.0 - INTRODUCTION.....	1
2.0 - EXECUTIVE SUMMARY	5
3.0 - EXPERIMENTAL	6
4.0 - RESULTS AND DISCUSSION.....	12
Task 1.0 - Research Management Plan	12
Task 2.0 - Technology Status Assessment	12
Task 3.0 - Review Operators Experience and Repair Needs	12
Task 4.0 - Evaluate Potential Repair Methods	17
5.0 - CONCLUSIONS.....	24
6.0 - REFERENCES.....	26
7.0 - BIBLIOGRAPHY	27
8.0 - LIST OF ACRONYMS	29
9.0 - APPENDICES	30
Appendix A - Draft Industry Survey	A-1
Appendix B - Members of the Pipeline Research Council International.....	B-1
Appendix C - List of Natural Gas Pipeline Operating Companies.....	C-1

Tables

	<u>Page</u>
Table 1	23

LIST OF GRAPHICAL MATERIALS

	<u>Page</u>
Figure 1 - Installation of a Full-Encirclement Repair Sleeve	1
Figure 2 - External Weld Deposition Repair of Internal Wall Loss in 90 Degree Elbow.....	2
Figure 3 - Osaka Gas System for Remote Robotic Internal Repair of Root Weld Defects in Gas Transmission Pipelines.....	2
Figure 4 - Clock Spring® Fiber-Reinforced Composite Device for Pipeline Repair	3
Figure 5 - Installation of a Sectional Liner in Low-Pressure Pipeline	4
Figure 6- RolaTube Bi-Stable Reeled Composite Material	6
Figure 7 - Lay-Up and Forming of Fiber-Reinforced Composite Liner	7
Figure 8 - Insertion of Liner into 114.3 mm (4.5 in.) Diameter Pipe	8
Figure 9 - Silicon Rubber Bag Inserted into Liner	8
Figure 10 - Oven Used to Heat Pipe and Liner to 200°C (392°F).....	9
Figure 11 - Liner Inserted into Center of 114.3 mm (4.5 in.) Diameter Pipe	9
Figure 12 - Long, Shallow Simulated Corrosion Damage	10
Figure 13 - Short, Deep Simulated Corrosion Damage	10
Figure 14 - 114.3 mm (4.5 in.) Diameter Pipe with End Caps Welded and Simulated Corrosion Damage Introduced	11
Figure 15 - Experimental Set-Up for Welding onto Thin-Wall Pipe containing Pressurized Methane Gas	14
Figure 16 - External Appearance of Welds Made on 3.2 mm (0.125 in.) Thick Pipe with Methane Gas at 4.5 mPa (650 psi) and 6.1 m/sec (19.9 ft/sec) Flow Rate	15
Figure 17 - Internal Appearance of Welds Shown in Figure 16	15
Figure 18 - Metallographic Section through Weld 2M9 (middle weld shown in Figure 16 and Figure 17)	16
Figure 19 - Eutectic Iron Layer at Inside Surface of Metallographic Section through Weld 2M9	16
Figure 20 - Cracks in Eutectic Iron Layer of Metallographic Section Shown in Figure 19	17
Figure 21 - Hydrostatic Test Rupture of Long, Shallow Simulated Corrosion Damage in Pipe Section Containing Fiber-Reinforced Composite Liner.....	19
Figure 22 - Hydrostatic Test Leak of Short, Deep Simulated Corrosion Damage in Pipe Section Containing Fiber-Reinforced Composite Liner.....	20
Figure 23 - Section Taken Hydrostatic Test Rupture of Long, Shallow Simulated Corrosion Damage in Pipe Section Containing Fiber-Reinforced Composite Liner	21
Figure 24 - Fiber-Reinforced Composite Liner in Ruptured Pipe Section Containing Long, Shallow Simulated Corrosion Damage Fiber-Reinforced Composite Repairs.....	21

1.0 - INTRODUCTION

Repair methods that can be applied from the inside of a gas transmission pipeline (i.e., trenchless methods) are an attractive alternative to conventional repair methods since the need to excavate the pipeline is precluded. This is particularly true for pipelines in environmentally sensitive and highly populated areas. Several repair methods that are commonly applied from the outside of the pipeline are, in theory, directly applicable from the inside. However, issues must be addressed such as development of the required equipment to perform repairs remotely and the mobilization of said equipment through the pipeline to areas that need to be repaired. Also, several additional repair methods that are commonly applied to other types of pipelines (gas distribution lines, water lines, etc.) have potential applicability but require further development to meet the requirements for repair of gas transmission pipelines.

Gas transmission pipeline repair by direct deposition of weld metal, or weld deposition repair, is a proven technology that can be applied directly to the area of wall loss (e.g., external repair of external wall loss - Figure 1) or to the side opposite the wall loss (e.g., external repair of internal wall loss – Figure 2).



Figure 1 - Installation of a Full-Encirclement Repair Sleeve



Figure 2 - External Weld Deposition Repair of Internal Wall Loss in 90 Degree Elbow

There are no apparent technical limitations to applying this repair method to the inside of an out-of-service pipeline. It is direct, relatively inexpensive to apply, and requires no additional materials beyond welding consumables. However, application of this repair method to the inside of an in-service pipeline would require that welding be performed in a hyperbaric environment. Deposited weld metal repairs are also used to repair circumferentially oriented planar defects (e.g., intergranular stress corrosion cracks adjacent to girth welds) in the nuclear power industry. Remote welding has been developed primarily by needs in the nuclear power industry, though working devices have been built for other applications, including repair of gas transmission pipelines. An example is shown in Figure 3.



Figure 3 - Osaka Gas System for Remote Robotic Internal Repair of Root Weld Defects in Gas Transmission Pipelines

Fiber-reinforced composite repairs are becoming widely used as an alternative to the installation of welded, full-encirclement sleeves for repair of gas transmission pipelines. These repairs typically consist of glass fibers in a polymer matrix material bonded to the pipe using an adhesive. Adhesive filler is applied to the defect prior to installation to allow load transfer to the composite material. The primary advantage of these repair products over welded, full-encirclement sleeves is the fact that welding is precluded. An illustration of the most commonly-used of the fiber-reinforced composite devices, Clock Spring®, is shown in Figure 4.



Figure 4 - Clock Spring® Fiber-Reinforced Composite Device for Pipeline Repair

A variety of liners are commonly used for repair of other types of pipelines (gas distribution lines, sewers, water mains, etc.). Of these, the three that are potentially applicable to internal repair of gas transmission pipelines are sectional liners, cured-in-place liners, and fold-and-formed liners. Sectional liners are typically 3 to 15 feet in length and are installed only in areas that require repairs. Cured-in-place liners and fold-and-formed liners are typically applied to an entire pipeline segment. Cured-in-place liners are installed using the inversion process, while fold-and-formed liners are pulled into place and then inverted so that they fit tightly against the inside of the pipe. The installation of a sectional liner is illustrated in Figure 5.

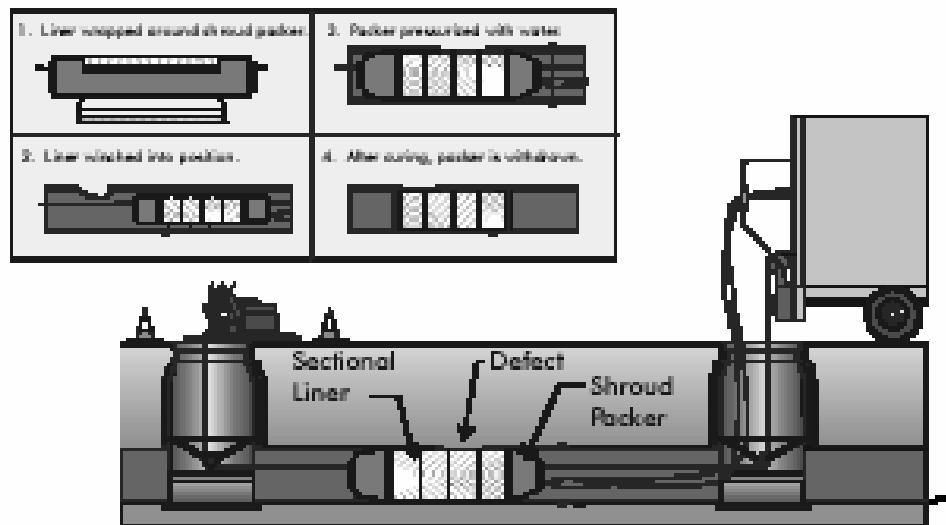


Figure 5 - Installation of a Sectional Liner in Low-Pressure Pipeline

2.0 - EXECUTIVE SUMMARY

The two broad categories of deposited weld metal repair and fiber-reinforced composite repair technologies were reviewed for potential application for internal repair of gas transmission pipelines. Both are used to some extent for other applications and could be further developed for internal, local, structural repair of gas transmission pipelines. Although both of these repair technologies can easily be applied out-of-service, both require excavation prior to repair.

The most frequent cause for repair of gas transmission pipelines was identified as external, corrosion-caused loss of wall thickness. The most commonly used in-service method for repair is welding on a full-encirclement steel sleeve. Weld deposition repair is a proven technology that can be applied directly to the area of wall loss. There are no apparent limitations to applying this repair technology to the outside of an out-of-service pipeline. Application of this repair to the inside of an in-service pipeline would require that welding be performed in a hyperbaric environment.

Fiber-reinforced composite repairs are becoming widely used as an alternative to welding. Three liners that are potentially applicable to internal repair of pipelines are sectional liners, cured-in-place liners, and fold-and-formed liners. External corrosion can also be repaired by applying adhesive to the defect and wrapping a fiber-reinforced composite material around the outside diameter of the pipeline.

Preliminary test programs were developed for both deposited weld metal repairs and for fiber-reinforced composite repair. Areas of damage were artificially introduced into pipe sections using methods previously developed at EWI. RoloTube developed a modified version of their fiber-reinforced composite with nine plies of glass-polypropylene in the form of overlapping pre-pregated tapes of unidirectional glass and polymer. These liners were inserted into two damaged pipe sections and two damaged pipe sections had no lining. All four damaged pipe sections were hydrostatically tested until rupture. The two pipes with liners failed at pressures only marginally greater than the pipe with no liner. It was determined that the liner material was not as elastic as the steel pipe and therefore not able to carry its share of the load. RoloTube is currently redesigning the liner with a carbon/polypropylene material that should carry a greater load. During the next reporting period, preliminary test programs for deposited weld metal repairs will be initiated and fiber-reinforced composite repairs will continue into the next phase of the project.

3.0 - EXPERIMENTAL

To date, all of the experimental work pertaining to the evaluation of potential repair methods has focused on fiber-reinforced composite repairs. This section describes all experimental methods used during this reporting period.

Task 2.0 research activities resulted in the discovery of several potentially useful commercial fiber-reinforced composite products that are directly applicable to internal repair. The initial test program is focusing on a modified Wellstream-Haliburton/RolaTube product, which is a bi-stable reeled composite material used to make strong, lightweight, composite pipes and pipe linings (Figure 6). When unreeled, it changes shape from a flat strip to an overlapping circular pipe liner that can be pulled into position. Following deployment, the longitudinal seam is welded with an adhesive that is activated and cured by induction heating. One example of this product is 100 mm (4 in.) diameter by 2.5 mm (0.10 in.) thick and is said to have a 60 bar (870 psi) short-term burst pressure.

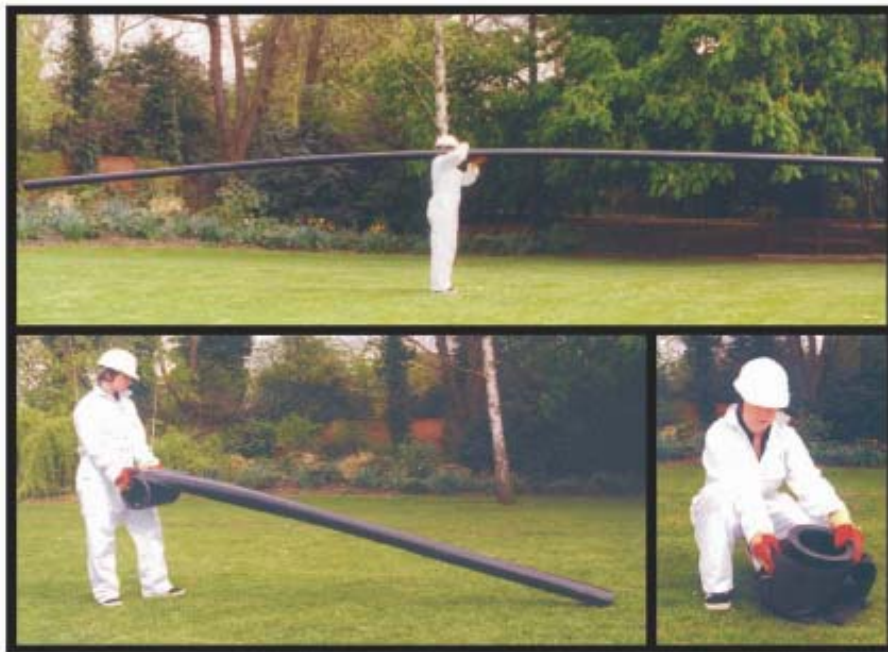


Figure 6- RolaTube Bi-Stable Reeled Composite Material

For the initial trials, RolaTube developed a modified version of the bi-stable reeled composite product which uses nine plies of a glass-polypropylene material in the form of

overlapping, pre-pregnated tapes of unidirectional glass and polymer. Glass-high density polyethylene (HDPE) material was also considered. The glass-polypropylene material was selected after problems bonding the glass-HDPE material to steel were encountered. Heat and pressure were used to consolidate the plies glass-polypropylene material into a liner (Figure 7). The resulting wall thickness of the liner is 2.85 mm (0.11 in.).



Figure 7 - Lay-Up and Forming of Fiber-Reinforced Composite Liner

A supply of 114.3 mm outside diameter (OD) x 4 mm wall thickness (4.5 in. OD x 0.156 in.) API 5L Grade B pipe material was procured and cut into four sections approximately 1.2 m (4 ft.) long. After the inside surface was degreased, lengths of lining were installed into two of the pipe sections (Figure 8). The installation process consisted of inserting a silicon rubber bag inside the liner (Figure 9) and locating the liner inside the pipe. The silicon bag was then inflated to press the liner against the pipe wall. For these experiments, the entire pipe sections were then heated to 200°C (392°F) in an oven (Figure 10) to fuse the liner to the pipe wall. Possible choices for liner installation in the field include infra-red (IR) heaters on an expansion pig or a silicon bag inflated using hot air. An installed liner is shown in Figure 11.



Figure 8 - Insertion of Liner into 114.3 mm (4.5 in.) Diameter Pipe



Figure 9 - Silicon Rubber Bag Inserted into Liner

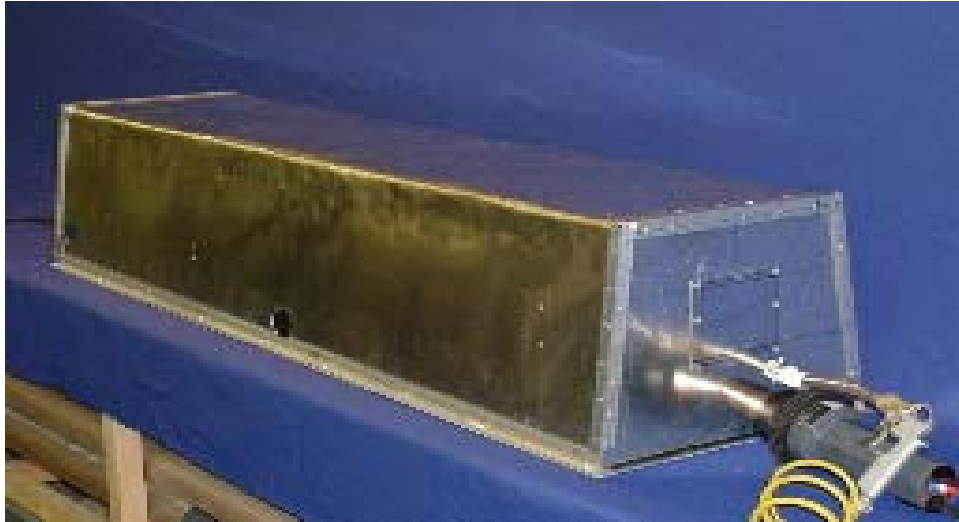


Figure 10 - Oven Used to Heat Pipe and Liner to 200°C (392°F)



Figure 11 - Liner Inserted into Center of 114.3 mm (4.5 in.) Diameter Pipe

Using the RSTRENG software,⁽¹⁾ dimensions of simulated general corrosion and a deep, isolated corrosion pit both with a 30% reduction in burst pressure were calculated then introduced into pipe sections with a milling machine. Using a ball end mill, long shallow damage representative of general corrosion (Figure 12) was introduced into one pipe section lined with fiber-reinforced composite pipe (FRCP) and one without. Using an end mill with rounded corners, short, deep damage representative of a deep isolated

corrosion pit (Figure 13) was introduced into the second pair of pipe sections; one lined, one not lined. End caps were then welded to all four of the pipe sections (Figure 14).



Figure 12 - Long, Shallow Simulated Corrosion Damage

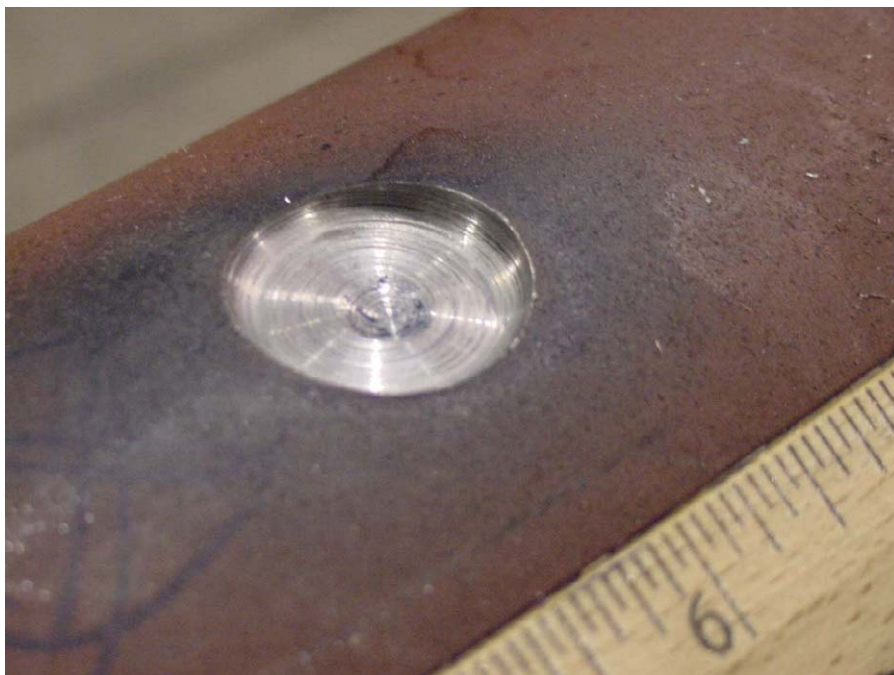


Figure 13 - Short, Deep Simulated Corrosion Damage



Figure 14 - 114.3 mm (4.5 in.) Diameter Pipe with End Caps Welded and Simulated Corrosion Damage Introduced

4.0 - RESULTS AND DISCUSSION

This report describes progress pertaining to a project sponsored by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) to develop internal repair technology for gas transmission pipelines. In order to thoroughly investigate repair technology, this project brings together a combination of partners that have a proven track record in developing pipeline repair technology. The project team consists of Edison Welding Institute (EWI), a full-service provider of materials joining engineering services; Pacific Gas & Electric (PG&E), a pipeline company that has a current need for the technology; and the Pipeline Research Council International (PRCI), an international consortium of pipeline companies, to provide project oversight and direction. EWI is the lead organization performing this Award for NETL located in Morgantown, West Virginia.

Task 1.0 - Research Management Plan

During this reporting period, the team created a Research Management Plan⁽²⁾. This document contains a work breakdown structure and supporting narrative that concisely summarizes the overall project. The plan is an integration of the technical and programmatic data into one document that details the technical objectives and technical approach for each task and subtask. The document also contains detailed schedules and planned expenditures for each task and all major milestones/decision points.

Task 2.0 - Technology Status Assessment

During this reporting period, a report⁽³⁾ was produced that presents the status of existing pipeline repair technology that can be applied to the inside of a gas transmission pipeline. This report describes the current state-of-the-art technologies that are being developed, including the positive and negative aspects of each technology.

Task 3.0 - Review Operators Experience and Repair Needs

This task consists of conducting a survey of pipeline companies to determine the situations where internal repair would be the preferred repair method for gas transmission pipelines. The intent of the survey is to determine the specific geographic locations and special situations where internal repairs would be most cost-effective.

Subtask 3.1 - Define Repair Needs and Performance Requirements

During this reporting period, a draft survey was developed (Appendix A). The survey is divided into the following parts:

- Currently-Used Repair Methods
- Use/Potential Use of Internal Repair
- Need for In-Service Internal Repair
- Applicable Types of Damage
- Operational and Performance requirements for Internal Repairs.

During the next reporting period, the draft industry survey will be finalized and sent to pipeline operating companies. This survey will primarily focus on pipeline operating companies (gas transmission) that are members of the Pipeline Research Council International (Appendix B). The survey will also be sent to other pipeline operating companies (Appendix C).

Following receipt of completed surveys, follow-up telephone calls will be made to further identify the range of pipeline sizes, materials and coating types in most common use and the types of pipeline damage and remediation/upgrades (to more stringent code requirements) that are most frequently encountered. The pipeline companies will also be asked to define specific operational and performance requirements for internal repairs, including post repair inspection and future pipeline inspection (i.e. pigging). The survey will also determine operating requirements such as the minimum and maximum distance a repair system needs to be able to travel inside a pipe to facilitate internal repair and potential obstructions such as elbows, bends, branches, and taps that may limit access.

Companies that offer in-line inspection services will also be surveyed to determine the maximum geometric variations associated with internal repairs (particularly internal build-up, liner thickness, etc.) that can be tolerated by current and next generation in-line inspection vehicles (a.k.a. smart pigs).

If the results of survey indicate that operators have a strong preference for the development of internal repair methods that can be applied while the pipeline remains in-service, a separate series of experiments will be carried out to investigate the effect of methane in the welding environment on the integrity of completed welds.

During any arc welding operation, the material being welded is exposed to temperatures that range from ambient to well above the melting temperature $1,536^{\circ}\text{C}$ ($2,736^{\circ}\text{F}$). When steel at high temperature is exposed to a hydrocarbon gas (such as methane), carburization can occur. When steel at temperatures above $1,130^{\circ}\text{C}$ ($2,066^{\circ}\text{F}$) is exposed to methane, eutectic iron can form as the result of diffusion of carbon from the methane into the steel. In previous work at EWI,⁽⁴⁾ in which welds were made on the outside of thin-wall pipe containing pressurized methane gas (Figure 15, Figure 16, and Figure 17), carburization and the formation of thin layer of eutectic iron occurred (Figure 18 and Figure 19). This phenomenon was previously reported by Battelle during experiments with liquid propane.⁽⁵⁾ There were also small cracks associated with the eutectic iron layer (Figure 20), which were attributed to the limited ductility of eutectic iron.



Figure 15 - Experimental Set-Up for Welding onto Thin-Wall Pipe containing Pressurized Methane Gas



Figure 16 - External Appearance of Welds Made on 3.2 mm (0.125 in.) Thick Pipe with Methane Gas at 4.5 mPa (650 psi) and 6.1 m/sec (19.9 ft/sec) Flow Rate



Figure 17 - Internal Appearance of Welds Shown in Figure 16

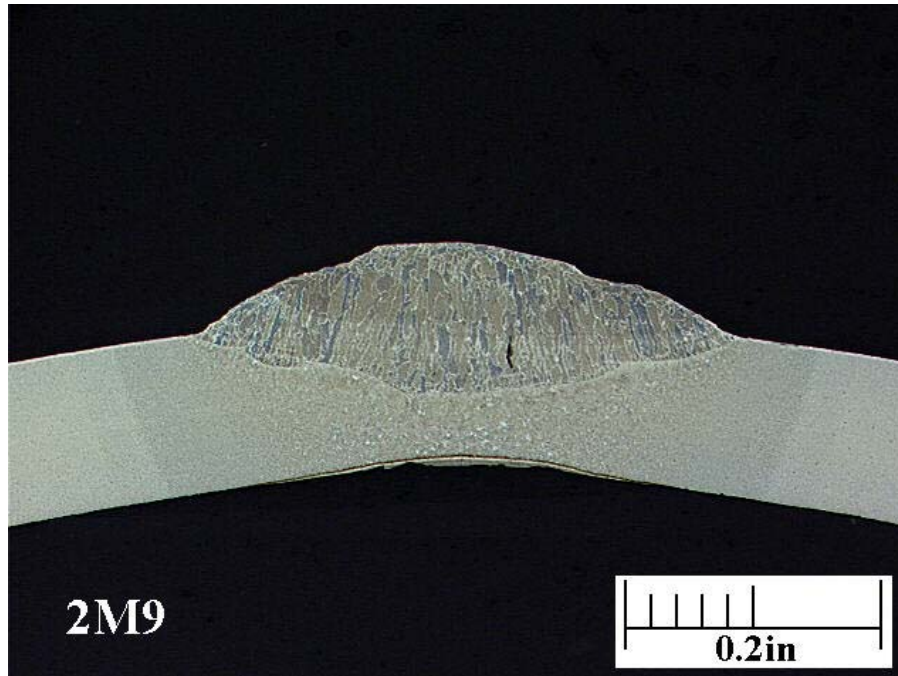


Figure 18 - Metallographic Section through Weld 2M9 (middle weld shown in Figure 16 and Figure 17)

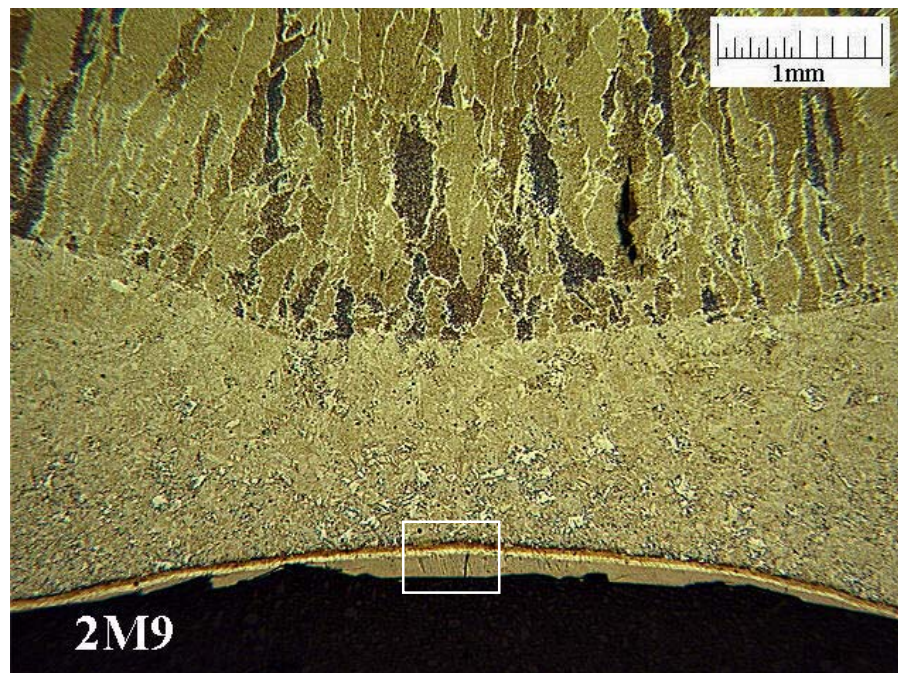


Figure 19 - Eutectic Iron Layer at Inside Surface of Metallographic Section through Weld 2M9

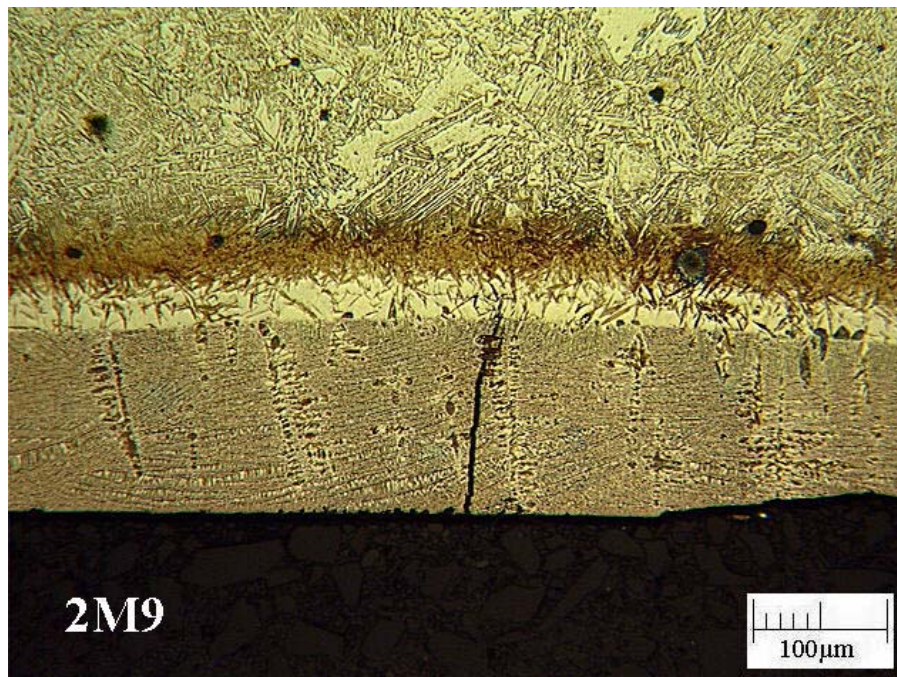


Figure 20 - Cracks in Eutectic Iron Layer of Metallographic Section Shown in Figure 19

Subtask 3.2 - Define Target Specifications for an Internal Pipeline Repair System

During this reporting period, there was no activity under this subtask. During the next reporting period, the results of the survey will be collected and analyzed to enable development of the target specification for an internal pipeline repair system.

Subtask 3.3 - Prepare Report "Summary of Industry Needs for Internal Pipeline Repair"

During this reporting period, there was no activity on Subtask 3.3, as Subtasks 3.1 and 3.2 must be completed before the report is written. During the next reporting period, EWI will prepare a draft report summarizing the Task 3.0 Review of Operators Experience and Repair Needs.

Task 4.0 - Evaluate Potential Repair Methods

This task will evaluate potential repair processes to assess their feasibility and suitability for internal pipeline repair. The results from the evaluation will be used to complete

Task 5.0. Consideration will be given to each method's applicability to planar or metal loss damage types and their suitability for in-service repair.

Subtask 4.1 - Identify Potential Repair Methods

During this reporting period, the Task 2.0 - Technology Status Assessment was used to identify two broad categories of repair technology that are potentially applicable to gas transmission pipelines from the inside. While it is anticipated that the results of the Task 3.0 survey will provide direction regarding which specific repair method should be emphasized in the experimental portion of the project, both deposited weld metal repairs and fiber-reinforced composite repairs are being investigated in the preliminary experiments in the Task 4.0 evaluation.

During the next reporting period, the preliminary test programs for deposited weld metal repairs will be initiated and fiber-reinforced composite repairs will continue, as outlined below.

Subtask 4.2 - Develop Internal Repair Test Program

During this reporting period, all of the experimental work pertaining to the evaluation of potential repair methods has focused on fiber-reinforced composite repairs.

Deposited Weld Metal Repairs

During this reporting period, a preliminary test program for deposited weld metal repairs was developed. This test program will initially focus on the ability of internal weld deposition repair to restore the integrity of pipe sections containing external corrosion-caused wall loss.

During the next reporting period, EWI will initiate this test program. A separate series of experiments to investigate the effect of methane in the welding environment on the integrity of completed weld will be planned and initiated, if the results of the Task 3.0 survey indicate that operators have a strong preference for the development of internal repair methods that can be applied while the pipeline remains in-service.

Fiber-Reinforced Liners

During this reporting period, a preliminary test program of small-scale experiments for fiber-reinforced composite repairs was developed and initiated in order to take advantage of existing tooling for the RolaTube product.

The two pipe sections with liners and the two without liners were hydrostatically pressurized to failure. The failure pressures are shown in Table 1.

Damage Description	Failure Pressure (psi)	
	No Liner	With Liner
Long, shallow	3,431	3,472
Short, deep	3,750	4,031

Table 1 - Hydrostatic Burst Test Results for Small-Scale Fiber-Reinforced Composite Liner Experiments

Ruptures were produced in the pipe sections containing long, shallow simulated corrosion damage (Figure 21). Leaks were produced in the pipe sections containing short, deep simulated corrosion damage (Figure 22).



Figure 21 - Hydrostatic Test Rupture of Long, Shallow Simulated Corrosion Damage in Pipe Section Containing Fiber-Reinforced Composite Liner

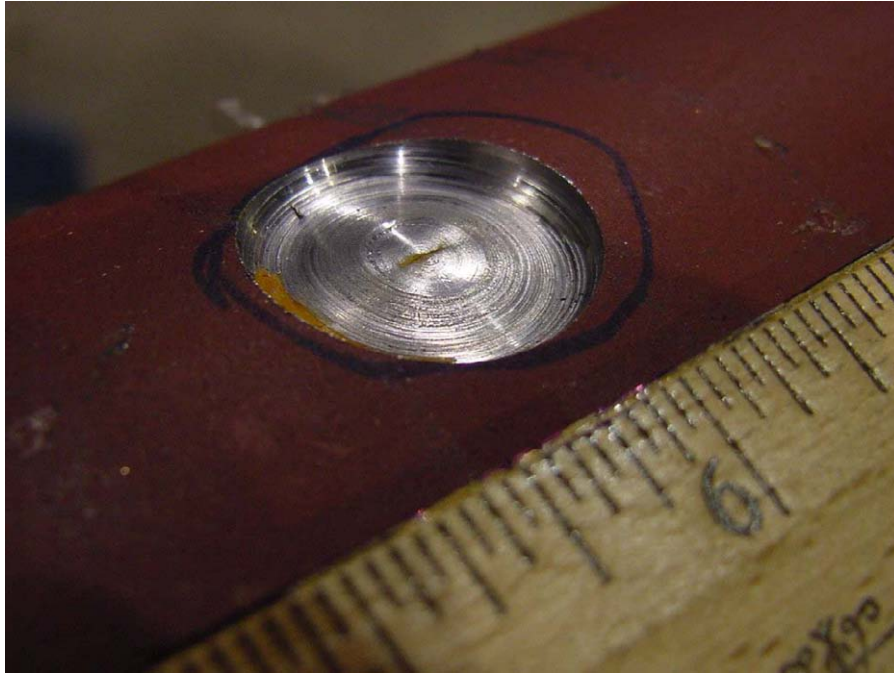


Figure 22 - Hydrostatic Test Leak of Short, Deep Simulated Corrosion Damage in Pipe Section Containing Fiber-Reinforced Composite Liner

In both cases (long, shallow and short, deep simulated corrosion damage), the failure pressure for the pipe with the liner was only marginally greater than the pipe without the liner. Postmortem analysis of the pipe section with the long, shallow damage revealed that the liner did rupture, indicating that disbonding was not an issue (Figure 23 and Figure 24). Analysis of the results indicates that the difference in modulus of elasticity between the steel and the liner material prevents the liner from carrying its share of the load. The liner is currently being redesigned by RolaTube using a carbon/polypropylene material instead of glass/polypropylene so that the modulus of elasticity is approximately 95% less than that of steel.



Figure 23 - Section Taken Hydrostatic Test Rupture of Long, Shallow Simulated Corrosion Damage in Pipe Section Containing Fiber-Reinforced Composite Liner



Figure 24 - Fiber-Reinforced Composite Liner in Ruptured Pipe Section Containing Long, Shallow Simulated Corrosion Damage Fiber-Reinforced Composite Repairs

During the next reporting period, additional small-scale experiments will be carried out using the redesigned fiber-reinforced composite liner material following the receipt of samples of lined pipe from RolaTube. Should the performance of this repair method continue to be less than desirable, the use of another type of liner-based repair, such as solid expandable tubulars, will be considered.

Subtask 4.3 - Simulation and Analysis of Potential Repair Methods

In previous work for PRCI,⁽⁶⁾ finite element analysis (FEA) was performed to simulate external weld deposition repair of internal wall loss. To supplement this work, plans were made for additional FEA to simulate internal weld deposition repair of external wall loss.

During this reporting period and prior to the initial trials for fiber-reinforced composite repairs, FEA was performed by RolaTube to determine the required properties of the liner material. Again, postmortem analysis of the pipe section damage indicates that the difference in modulus of elasticity between the steel and the liner material prevents the liner from carrying its share of the load. RolaTube is currently using FEA to redesign the liner with a carbon/polypropylene material instead of glass/polypropylene material.

For the next reporting period, EWI will conduct FEA where appropriate, to model the welding repair methods and guide the baseline parameters for the weld repair development trials. An example such FEA work would be to model the relationship between weld heat input and the temperature on the outside surface of the pipe to predict the behavior of the pipe coating.

Subtask 4.4 - Internal Repair Evaluation Trials

During this reporting period, all of the experimental work pertaining to the evaluation of potential repair methods has focused on fiber-reinforced composite repairs.

During the next reporting period, areas of damage will be artificially introduced into sections of pipe using methods previously developed at EWI. The artificially introduced damage will then be repaired using mechanized gas metal arc welding (GMAW). Repairs will be made while the pipe sections are contained within a soil box so that the ability of the soil to remove heat from the pipe wall is simulated. The pipe sections will consist of older vintage line pipe material, typical of pipelines currently in service that

frequently require repair. A supply of material that fits this description is currently on hand at EWI. The diameters of these materials range from 508 to 914 mm (20 to 36 in.). All significant data pertinent to each repair method (e.g., welding parameters, etc.) will be recorded during the development trials.

Following the completion of the repairs, metallographic examination and mechanical testing will be carried out. The effect of temperature on the integrity of external coatings will then be investigated. A limited number of hydrostatic burst tests will also be carried out.

Subtask 4.5 - Prepare Report "Review and Evaluation of Internal Pipeline Repair Technologies"

Again, during this reporting period preliminary experimental work was conducted to produce data for this report.

During the next reporting period, EWI will produce the Task 4.0 - Evaluation of Potential Repair Methods draft report containing a detailed analysis of the development trial results. The report will include a matrix listing capabilities and/or limitations of each repair method, and recommendations of potential repair methods that should be included in the next phase of the project.

Task 5.0 - Optimize and Validate Internal Repair Methods

Task 4.0 is prerequisite to Task 5.0, therefore, no activity occurred during this reporting period.

During the next reporting period, preliminary plans will be made for this task, which will involve optimizing the most promising repair technologies and verifying pipeline performance by full-scale tests.

5.0 - CONCLUSIONS

The most common cause for repair of gas transmission pipelines is external, corrosion-caused loss of wall thickness.⁽⁷⁾ To prevent an area of corrosion damage from causing a pipeline to rupture, the area containing the corrosion damage must be reinforced. Other pipeline defects that commonly require repair include internal corrosion, original construction flaws, service induced cracking, and mechanical damage.

Defects oriented in the longitudinal direction have a tendency to fail from hoop stress (pressure loading) and must be reinforced in the circumferential direction. Defects oriented in the circumferential direction have a tendency to fail from axial stresses (e.g., pipeline settlement) and must be reinforced in the longitudinal direction. Full-encirclement steel repair sleeves resist hoop stress and, if the ends are welded to the pipeline, can also resist axial stresses.

The Task 2.0 - Technology Status Assessment indicates that the most commonly used method for repair of gas transmission pipelines is the full-encirclement steel repair sleeve (Figure 1). This and other repair methods commonly applied from the outside of the pipeline are typically done so while the pipeline remains in-service. While this would be desirable for internal repair, many of the repair methods that are applicable to the inside of the pipeline would require that the pipeline be taken out-of-service. Most of the repair methods that are commonly applied to the inside of other types of pipelines, which typically operate at low pressure, are done so to restore leak tightness. These repair methods would require further development in order for them to restore the strength of a gas transmission pipeline.

The two broad categories of deposited weld metal repair and fiber-reinforced composite repair technologies were identified for potential application for internal repair of gas transmission pipelines. Both are used to some extent for other applications and could be further developed for internal, local, structural repair of gas transmission pipelines. The specific development needs for these repair technologies can be summarized as follows.

The important characteristics of a useful internal weld repair system include the ability to operate at long range from the pipe entry point (i.e., 2,000 ft. or more), the agility to transverse bends and miters, a machining capability to prepare the weld joint, a grinding system for cleaning and preparation, and a high deposition robust welding process.

Although many of these features are incorporated in the existing systems, there is no single system that possesses all the required characteristics. Further work is required to develop a system with all of these features.

Further development of fiber-reinforced composite repairs/liners with sufficient strength is required prior to application to internal, local structural repair of gas transmission pipelines. Ideally, these products would combine the strength of currently used external repair products or composite reinforced line pipe (CRLP) with the installation process currently used for liners in other types of pipelines. Adhesion of the liner to the pipe surface, which is important for structural reinforcement but not restoration of leak tightness, also needs to be addressed. The required thickness of a repair for structural reinforcement and the potentially adverse effect on internal inspection and flow restriction is another issue to be addressed.

6.0 - REFERENCES

- (1) Kiefner, J. F. and Vieth, P. H., "A Modified Criterion for Evaluating the Remaining Strength of Corroded Pipe" Final Report to A.G.A. Pipeline Corrosion Supervisory Committee, Project PR-3-805, Battelle, Columbus, OH, December 1989.
- (2) Gordon, J. R., Bruce, W. A., and Porter, N. C., "Internal Repair of Pipelines – Research Management Plan," Report to National Energy Technology Laboratory, U.S. Department of Energy, DOE Award No.: DE-FC26-02NT41633, Edison Welding Institute, October 2002.
- (3) Gordon, J. R., Bruce, W. A., Sullivan, M., and Neary, C. M., "Internal Repair of Pipelines – Technology Status Assessment," Report to National Energy Technology Laboratory, U.S. Department of Energy, DOE Award No.: DE-FC26-02NT41633, Edison Welding Institute and Pacific Gas & Electric, November 2002.
- (4) Bruce, W. A., "Welding onto In-Service Thin Wall Pipelines," Final Report for EWI Project No. 41732CAP to PRC International, Contract No PR-185-9908, July 2000.
- (5) Kiefner, J. F., Barnes, C. R., Gertler, R. C., Fischer, R. D., and Mishler, H. W., "Experimental Verification of Hot Tap Welding Thermal Analysis. Final Report - Phase II - Volume 2, Liquid Propane Experiments," Repair and Hot Tap Welding Group, Battelle Columbus Laboratories, May 1983.
- (6) Wang, Y.-Y., and Bruce, W. A., "Examination of External Weld Deposition Repair for Internal Wall Loss," Final Report for EWI Project No. 07723CAP to PRC International, Contract No PR-185-9633, March 1998.
- (7) Eiber, R. J., Bubenik, T. A., and Leis, B. N., "Pipeline Failure Mechanisms and Characteristics of the Resulting Defects," Eighth Symposium on Line Pipe Research, Paper No. 7 (Houston, TX: American Gas Association, 1993).

7.0 - BIBLIOGRAPHY

Bruce, W. A., "Welding onto In-Service Thin Wall Pipelines," Final Report for EWI Project No. 41732CAP to PRC International, Contract No PR-185-9908, July 2000. This report discusses special welding difficulties and the extra care required to ensure safe operating procedures and sound welds due to repairs and modifications to in-service, thin walled pipelines.

Eiber, R. J., Bubenik, T. A., and Leis, B. N., "Pipeline Failure Mechanisms and Characteristics of the Resulting Defects," Eighth Symposium on Line Pipe Research, Paper No. 7 (Houston, TX: American Gas Association, 1993). This report discusses four broad categories of pipeline failure mechanisms: outside forces, environmentally induced defects, manufacturing/materials defects, and operator error or miscellaneous defects.

Gordon, J. R., Bruce, W. A., and Porter, N. C., "Internal Repair of Pipelines – Research Management Plan," Report to National Energy Technology Laboratory, U.S. Department of Energy, DOE Award No.: DE-FC26-02NT41633, Edison Welding Institute, October 2002. This plan contains a concise summary of the technical objectives and approach for each task. The document also contain detailed schedules and planned expenditures for each task and all major milestones and decision points for the two year project duration.

Gordon, J. R., Bruce, W. A., Sullivan, M., and Neary, C. M., "Internal Repair of Pipelines – Technology Status Assessment," Report to National Energy Technology Laboratory, U.S. Department of Energy, DOE Award No.: DE-FC26-02NT41633, Edison Welding Institute and Pacific Gas & Electric, November 2002. This report presents the status of existing pipeline repair technology that can be applied to the inside of gas transmission pipelines, and includes results from a comprehensive computerized literature search, together with information obtained from discussions with companies that are currently developing or evaluating novel pipeline repair methods.

Kiefner, J. F., Barnes, C. R., Gertler, R. C., Fischer, R. D., and Mishler, H. W., "Experimental Verification of Hot Tap Welding Thermal Analysis. Final Report - Phase II - Volume 2, Liquid Propane Experiments," Repair and Hot Tap Welding Group, Battelle Columbus Laboratories, May 1983. This report documents the

verification of two thermal analysis models of hot tap welding on pressurized pipelines. With velocity input modified as shown, the models are capable of predicting maximum temperatures in the pipe wall especially at the inside surface and critical cooling rates in the heat-affected zones within the range of heat inputs that are practical for shielded metal arc welding.

Kiefner, J. F. and Vieth, P. H., "A Modified Criterion for Evaluating the Remaining Strength of Corroded Pipe" Final Report to A.G.A. Pipeline Corrosion Supervisory Committee, Project PR-3-805, Battelle, Columbus, OH, December 1989. This report documents a modified criterion for evaluating the corrosion level of a pipeline based on pipeline stress calculations (available as a PC program) as a less conservative alternative to ANSI / ASME B31G.

Wang, Y.-Y., and Bruce, W. A., "Examination of External Weld Deposition Repair for Internal Wall Loss," Final Report for EWI Project No. 07723CAP to PRC International, Contract No PR-185-9633, March 1998. This report discusses the deposition of weld metal on the external surface of straight sections of pipe, field bends, tees and elbows as a potentially useful method for in-service repair of internal wall loss.

8.0 - LIST OF ACRONYMS

ASME	American Society of Mechanical Engineers
ANSI	American National Standards Institute
CAE	Computer Aided Engineering
CRLP	Composite Reinforced Line Pipe
DOE	Department of Energy
EWI	Edison Welding Institute
FEA	Finite Element Analysis
FRCP	Fiber-Reinforced Composite Pipe
Glass-HDPE	Glass-High Density Polyethylene
GMAW	Gas Metal Arc Welding
HDPE	High Density Polyethylene
IR	Infra-Red
NDE	Nondestructive Evaluation
NETL	National Energy Technology Laboratory
OD	Outside Diameter
PC	Personal Computer
PG&E	Pacific Gas & Electric
PRCI	Pipeline Research Council International

9.0- APPENDICES

Appendix A

Draft Industry Survey with Cover Letter

April 11, 2003

<<<FIELD 1>>>

EWI Project No. 46211GTH, "Internal Repair of Pipelines"

Dear <<<FIELD 2>>>:

Enclosed is a survey of operator experience and industry needs pertaining to internal repair of pipelines. EWI is conducting this survey as part of a project being funded by the National Energy Technology Laboratory. The objectives of this project are to evaluate, develop, demonstrate, and validate internal repair methods for pipelines.

Please complete this survey at your earliest convenience.¹ Your participation is greatly appreciated. If you have questions or require additional information, please contact me at 614-688-5059 or bill_bruce@ewi.org

Sincerely,

William A. Bruce, P.E.
Principal Engineer
Materials section

Enclosure

¹ A copy of this survey was also sent to <<<FIELD 3>>> at your company. You may want to coordinate your response.

Internal Repair of Pipelines Survey of Operator Experience and Industry Needs

conducted for:

**National Energy Technology Laboratory
Morgantown, WV**

Project No. 46211GTH

on

**Internal Repair of Pipelines – Survey of
Operator Experience and Industry Needs**

for

National Energy Technology Laboratory
Morgantown, WV

April 11, 2003

EWI
1250 Arthur E. Adams Drive
Columbus, OH 43221

Internal Repair of Pipelines – Survey of Operator Experience and Industry Needs

1.00 Introduction

A repair method that can be applied from the inside of a gas transmission pipeline (i.e., a trenchless repair) is an attractive alternative to conventional repair methods since the need to excavate the pipeline is precluded. This is particularly true for pipelines in environmentally sensitive and highly populated areas. Several repair methods that are commonly applied from the outside of the pipeline are, in theory, directly applicable from the inside. However, issues such as development of the required equipment to perform repairs remotely and mobilization of equipment through the pipeline to areas that require repair need to be addressed. Several additional repair methods that are commonly applied to other types of pipelines (gas distribution lines, water lines, etc.) also have potential applicability for internal repair of gas transmission pipelines. Many of these require further development to meet the requirements for repair of gas transmission pipelines. The objectives of a project being funded by the National Energy Technology Laboratory are to evaluate, develop, demonstrate, and validate internal repair methods for pipelines; develop a functional specification for an internal pipeline repair system; and prepare a recommended practice for internal repair of pipelines. One of the initial tasks of this project involves conducting a survey to determine the repair needs and performance requirements for internal pipeline repairs. The purpose of this survey is to better understand the needs of the natural gas transmission industry regarding internal repair.

2.00 Instructions

Please respond as completely as possible to as many questions as possible. Space is also provided for any comments that you may have.

3.00 Survey

3.1 Part 1 – Currently-Used Repair Methods

1. Has your company experienced degradation (corrosion, cracking, etc) of a transmission line?

If so, has your company replaced or repaired pipe because of degradation?
2. What specific repair methods would typically be used to repair different types of degradation?

3.

Comments pertaining to currently-used repair methods –

3.2 Part 2 – Use/Potential Use of Internal Repair

1. Has your company attempted repair of a transmission line from inside the pipe?

If so, describe the repair(s)

2. There are many factors that affect the decision to repair or replace pipe. What circumstances would favor performing a repair from inside the pipe using only one or two excavations rather than excavating the entire length of pipe?

3. If the technology were available to perform a repair from the inside, would your company consider using the technology?

If so, for what application(s) – e.g., specific geographic locations and special situations?

4. At least one excavation will be required to insert the internal repair device into the pipe. From this excavation, the repair device could be travel in each direction from the excavation. About how far from the insertion point should the repair device be able to travel?

What range of pipe diameters should the repair device be capable of operation in?

5. What potential obstructions such as elbows, bends, branches, and taps should the repair system be able to negotiate?

6.

Comments pertaining to the use/potential use of internal repair –

3.3 Part 3 – Need for *In-Service* Internal Repair

1. How important is the ability to perform a repair from the inside the pipe while the pipeline remains in service?
2. Would internal repair remain attractive if it was necessary to completely shut down the pipeline (depressurized and evacuated) during the repair?

Depressurized but not evacuated?

Out of service (no flow) but remain pressurized?

- 3.

Comments pertaining to the need for in-service internal repair –

3.4 Part 4 – Applicable Types of Damage

1. What types of external coatings would be found on transmission lines owned by your company?
2. If a repair involving welding from the inside was performed, how important is it to preserve the integrity of the coating?

Is your cathodic protection system capable of compensating for relatively small breaches in the coating?

- 3.

Comments pertaining to applicable types of damage –

3.5 Part 5 – Operational and Performance requirements for Internal Repairs

1. Two general categories of repairs are being considered, (1) using weld metal to restore a surface and (2) installing an internal sleeve, either metallic or nonmetallic,

to provide structural reinforcement of leak tightness. Is it important that the line remain inspectable by pigging after repair?

About how far could the repair protrude into the pipe before it would interfere with pigging?

2. What NDE would your utility require for a repair to an existing longitudinal or circumferential weld?

Could a visual or magnetic particle examination be substituted for radiography in these special circumstances?

What NDE would your utility require for a welded repair to base metal (e.g. corrosion pitting)?

3. Would the use of internal repair be attractive even if it were considered a temporary repair

- 4.

Comments pertaining to operational and performance requirements for internal repairs –

3.6 General Comments

Please provide any general comments that you may have.

Appendix B

Members of the Pipeline Research Council International

Members of the Pipeline Research Council International

Advantica Technologies Ltd
BP
Buckeye Pipe Line Company
Chevron Texaco Pipeline Company
CMS Panhandle Companies
Colonial Pipeline Company
Columbia Gas Transmission Co.
ConocoPhillips
Consumers Energy
Dominion Transmission
Duke Energy Gas Transmission
El Paso Corporation
Enbridge Pipelines
Enron Transportation Services Corp.
Explorer Pipeline Company
ExxonMobil Pipeline Company
Foothills Pipe Lines Ltd
Gassco A.S. (Norway)
Gasum Oy (Finland)
Gaz de France
Gulf South Pipeline
Marathon Ashland Pipe Line LLC
N.V. Nederlandse Gasunie/Gastransport Services (The Netherlands)
National Fuel Gas Supply Corporation
Saudi Aramco
Sempra Energy Utilities/Southern California Gas Company
Shell Pipeline Company LP
Southern Natural Gas Company
TEPPCO
TransCanada PipeLines Limited
Transco (UK)
TransGas
Williams Gas Pipeline

Appendix C

List of Natural Gas Pipeline Operating Companies
(from <http://www.ferc.gov/gas/pipecomp.htm>)

List of Natural Gas Pipeline Operating Companies

Algonquin Gas Transmission Company
Algonquin LNG, Inc.
ANR Pipeline Company
ANR Storage Company
Black Marlin Pipeline Company
Blue Lake Gas Storage Company
Canyon Creek Compression Company
Carnegie Interstate Pipeline Company
Chandeleur Pipe Line Company
Colorado Interstate Gas Company
Columbia Gas Transmission Corporation
Columbia Gulf Transmission Company
Cove Point LNG Limited Partnership
Crossroads Pipeline Company
Discovery Gas Transmission LLC
Dominion Transmission Inc.
Dynegy Midstream Pipeline, Inc.
East Tennessee Natural Gas Company
Egan Hub Partners, L.P.
El Paso Natural Gas Company
Equitrans, Inc.
Florida Gas Transmission Company
Gas Transport, Inc.
Granite State Gas Transmission, Inc.
Great Lakes Gas Transmission Limited Partnership
Gulf South Pipeline
Gulf States Transmission Corporation
High Island Offshore System
Iroquois Gas Transmission System, L.P.
Kansas Pipeline Company
Kentucky West Virginia Gas Company
Kern River Gas Transmission Company
KM Interstate Gas Transmission Co.
KN Wattenberg Transmission
Maritimes & Northeast Pipeline L.L.C.
Michigan Gas Storage Company
Midwestern Gas Transmission Company
MIGC, Inc.
Mississippi River Transmission Corporation
Mojave Pipeline Company
National Fuel Gas Supply Corporation
Natural Gas Pipeline Company of America
Nora Transmission Company
Northern Border Pipeline Company
Northern Natural Gas Company

Northwest Pipeline Corporation
OkTex Pipeline Company
Overthrust Pipeline Company
Ozark Gas Transmission System
Paiute Pipeline Company
Panhandle Eastern Pipe Line Company
Petal Gas Storage Company
PG&E Gas Transmission-Northwest Corporation
Questar Pipeline Company
Reliant Energy Gas Transmission Company
Sabine Pipe Line Company
Sea Robin Pipeline Company
Shell Offshore Pipelines
South Georgia Natural Gas Company
Southern Natural Gas Company
Southwest Gas Storage Company
Steuben Gas Storage Company
TCP Gathering Co.
Tennessee Gas Pipeline Company
Texas Eastern Transmission Corporation
Texas Gas Transmission Corporation
Total Peaking LLC
Trailblazer Pipeline Company
TransColorado Gas Transmission Company
Transcontinental Gas Pipe Line Corporation
Transwestern Pipeline Company
Trunkline Gas Company
Trunkline LNG Company
Tuscarora Gas Transmission Company
U-T Offshore System
Vector Pipeline
Venice Gathering System, L.L.C.
Viking Gas Transmission Company
Williams Gas Pipelines Central, Inc.
Williston Basin Interstate Pipeline Company
Wyoming Interstate Company, Ltd.
Young Gas Storage Company, Ltd.