**November 27, 2002**
**EWI Project No. 46211GTH**
**Electronic File Name: 41633R07.pdf**

# Internal Repair of Pipelines
# Technology Status Assessment Report

Reporting Period
October 30, 2002 through November 22, 2002

Principal Authors:
Bill Bruce & Robin Gordon of EWI
and
Mike Sullivan & Chris Neary of PG&E

Report Issued
November 27, 2002

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

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## 1.0 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. This report presents the status of existing pipeline repair technology that can be applied to the inside of a gas transmission pipeline. The report 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.

## 2.0 Background

The most common cause for repair of gas transmission pipelines is external, corrosion-caused loss of wall thickness. 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 that have a tendency to fail from hoop stress (pressure loading) must be reinforced in the circumferential direction, while defects oriented in the circumferential direction that have a tendency to fail from axial stresses (e.g., pipeline settlement) must be reinforced in the longitudinal direction. The most commonly used method for repair of gas transmission pipelines is the full-encirclement steel repair sleeve. These sleeves resist hoop stress and, if the ends are welded to the pipeline, can resist axial stresses.

Current repair methods that are 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 typically require further development to restore the strength of a gas transmission pipeline.

## 3.0 Review and Assessment of Candidate Repair Methods

A review of common external repair methods for gas transmission pipelines and repair methods that are commonly applied to the inside of other types of pipelines resulted in the identification of two broad categories that are potentially applicable to repair of gas transmission pipelines from the inside:

- Weld Repair
- Fiber Reinforced Composite Repair

### 3.1 Weld Repairs

General - 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) or to the side opposite the wall loss (e.g., external repair of internal wall loss). There are no apparent technical limitations to applying this repair method to the inside of an out-of-service pipeline. Application of this repair method to the inside of an in-service pipeline would require that the welding be carried out in a hyperbaric environment, however. It is direct, relatively inexpensive to apply, and requires no additional materials beyond welding consumables. 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:

Osaka Gas has developed remote robotic equipment for repair of flaws in the root area of welds of gas transmission lines. Work on the equipment dates back to 1985. The robot is self-propelled via wheels with umbilical cable for control and power and is able to perform work up to 500 ft from the pipeline entry point. The power supply for welding equipment is located at the entry point, which limits the working range. The working range is also limited by the ability of the robot to pull the umbilical cable. The robot is capable of working in 12 to 24 in. diameter pipe with 90° bends. It does not remove the root flaws from the pipe prior to welding; it is limited to grinding of the pipe wall to remove impurities that can disrupt the welding arc. Welding is performed using the gas metal arc welding (GMAW) process and the torch travel path is programmed prior to welding. Welding filler metal is carried onboard, while shielding gas is supplied via the umbilical. The robot incorporates features such as wire cutting and nozzle cleaning. All inspection is visual using video cameras located on the robot. Welding is controlled to avoid damage to pipeline coating. Approximately 4 hours are required to grind, weld, and inspect a 24 in. weld. Osaka Gas has been using the robots to perform field repairs since 1995. Continuing development work is believed to focus on improving arc stability and robot range by placing the welding power supply on the robot.

Welding Services, Incorporated has developed a series of welding devices for remote welding. Of these, the device most applicable to pipeline repair is a machine developed for remote weld cladding of Cold Reheat Piping in nuclear power plants. The machine has no locomotive capability as the pipe sections to be clad are large in diameter (42 in. is common) and have nearby access, permitting technicians to assemble the machine within the pipe section to be clad. Each weld bead is deposited axially along the pipe for distances up to 12 ft. and then the weld head steps a short distance in the circumferential direction and begins depositing the next bead. This process is continued until the entire inside surface is clad. All welding is controlled remotely via video feed. High reliability and high weld deposition rates have been demonstrated with this machine, and thousands of pounds of weld metal have been deposited since its introduction. The machine has no machining or inspection capability since pipe sections are manually cleaned by abrasive blasting prior to welding and visual inspection can be performed after welding.

Honeybee Robotics and Consolidated Edison are developing the WISOR (Welding and Inspection Steam Operations Robot) system for inspection and repair of flanges in steam piping. Development commenced in 1995 and the system is expected to enter field trials in the near future. The robot is self-propelled using tracks with an umbilical cable for control and power. It is designed to operate in the presence of steam at temperatures up to 275°F and can perform work up to 135 ft. from the pipeline entry point. The power supply for the welding equipment is located at the entry point, which limits the working range. The robot is capable of working in 16 to 24 in. diameter pipe. A grinding operation is used to prepare a ¼-in. deep weld groove. Welding is performing using GMAW process and the torch is manually controlled. A steam guard is incorporated into the robot to allow welding in the presence of residual steam. Welding filler metal is carried onboard, while shielding gas is supplied via the umbilical. All inspection is visual using video cameras located on the robot.

Fermi National Accelerator Laboratory has developed their VRW (Visual Robotic Welding) system for the repair of highly radioactive proton beam transport pipes. The prototype system was developed in 1998 and is successfully performing field repairs. Most repairs performed have involved depositing weld metal to seal leaks from corrosion, but one repair was made by welding a small patch plate in place. The welding control system is innovative in that the GMAW welding gun is mounted on a robotic arm that duplicates the movements of an operator using a control arm to simulate welding a mockup of the work area. The robot is towed into position with umbilical cable for control and power and is capable of traversing straight pipe only. Work can be performed in excess of 1000 ft. from the pipeline entry point. Preliminary conceptual work was done to allow welding at distances up to 10,000 ft. The robot is capable of working in 12 to 18 in. diameter pipe and can prepare surfaces for welding by grinding or wire brushing, using an arm controlled in the same manner as the welding. Welding is performing using GMAW process. All inspection is visual using video cameras located on the robot.

Pacific Gas and Electric Company (PG&E) has developed the IPNS (Internal Pipeline NDE System) for internal inspection of gas pipelines. The system incorporates a variety of inspection technologies to characterize girth and long seam flaws, corrosion, and dents and gouges. The system also incorporates a grinder for preparation of areas of interest. The system has been in field use since 1996 and has a maximum range of 2500 ft. The robot is self-propelled using tracks and is able to traverse 90° bends in pipe from 22 to 24 inches in diameter. An umbilical is used to supply power and to control the device. Preliminary development work was performed for a companion system to perform machining and welding of defective welds. While not a welding system, IPNS demonstrates the practicality of performing work inside gas pipelines at extended distances from the entry point.

Siemens AG, Nuclear Power Generation in Erlangen, Germany has developed and deployed a family of robotic equipment for making repairs to the inside of piping for the nuclear power industry. The equipment can be inserted into the pipe through a disassembled valve and can move through 6 to 40 in. diameter pipe for a distance of 80 meters, or more, at speeds up to 15 ft./min. It can travel through multiple, 90°, short radius elbows. It consists of one or more driving modules and one working module joined by flexible couplings. Power, control and communication are provided through an umbilical attached to the rear of the last driving module. The system has been used to perform remote inspection, machining, and welding. This system is very flexible and can be configured for a variety of inspection, machining, welding, and object retrieval tasks. It is designed specifically to operate in power plant piping and is not capable of traveling long distances needed for pipeline repair. The equipment includes interchangeable wheeled or "inch-worm" driving modules that are capable of horizontal or vertical travel. Interchangeable working modules are capable of milling, grinding, gas tungsten arc welding (GTAW) welding, debris removal, visual inspection and eddy current and ultrasonic inspection.

### 3.2 Fiber-Reinforced Composite Repairs/Liners

General - 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 that the need for welding is precluded.

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 ft. 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. In addition to repair, continuously-applied liners could be used to increase the operating pressure (i.e. up-rate) an existing pipeline.

Composite reinforced line pipe (CRLP) is also being considered for new construction of gas transmission pipelines. CRLP is a patented process that applies glass-resin reinforcement to steel pipe, which forms an outer protective barrier with additional hoop strength, prior to installation. In the winter of 2001, a 2 km section of a 24 in. outside diameter (OD) CRLP pipe was installed in northwestern Canada and is presently being tested by TransCanada Pipelines. Composite reinforced pressure vessels are also being developed for gas transport modules (GTMs), which can be used to transport stranded gas to market areas. Composite materials are also being used for coiled tubing and offshore risers.

External Repair Methods – The three fiber-reinforced composite devices most commonly used for external repair of gas transmission pipelines are the Clock Spring®, StrongBack®, and Armor Plate® methods.

- Clock Spring® is a coil of high-strength composite material whose configuration allows it to wrap tightly around the pipe. When properly installed, the resulting repair provides circumferential reinforcement of the corroded area. The first units were placed in service in the 1980s. Over 50,000 permanent repairs have been made with the Clock Spring® system. Because the fibers are oriented uniaxially, Clock Spring® devices are not recommended for repair of circumferentially oriented defects. The Clock Spring® device in its present form is not suited to internal repair.
- StrongBack® is a resin-impregnated tape wrap that is applied directly to the prepared damaged pipeline area. The wrap is activated by immersion in water or external application of water and thus has the advantage of being applicable to wet lines.
- Armor Plate® Pipe Wrap Repair is similar to StrongBack®, except that the hardening agent is chemical rather than water activated.

Internal Repair Methods - The repair methods that are applicable for internal repair of pipelines include cured-in-place liners, fold-and-formed liners, and bi-stable reeled composite pipe liners.

- Cured-in-place pipe (CIPP) liners typically consist of a resin-impregnated felt tube. The inversion process is driven by either air or water pressure which results in the tube fitting tightly against the inside of the pipe. Depending on the product, the resin is cured using heated water or steam, or heat from one of a variety of other sources. Most of these products are intended to restore leak-tightness only. Several products could potentially be used to restore strength, one of which is manufactured by Inpipe in Sweden. Instead of felt, the Inpipe system uses braided tube consisting of resin-impregnated glass fibers. Once in place, the tube is cured using ultraviolet light. The cured liner is reported to have a tensile strength of 130 MPa (18.8 ksi) and a modulus of elasticity of 10,000 MPa (1,450 ksi). Another cured-in-place product that contains glass fibers is manufactured by IHC™ Rehabilitation Products in Pinehurst, Texas, which incorporates a technology known as Intralaminar Heat Cure or IHC™. IHC hybrid composites contain conductive elements that cure the laminate through resistive heating. In 1995, Pacific Gas & Electric (PG&E) began an exhaustive program to evaluate the performance of CIPP liners for gas distribution main and service applications. The program focused on the Paltem liner developed by Insituform Technologies in Chesterfield, Missouri, which is also based on a braided tube design. While the program was a technical success, PG&E concluded that a number of obstacles must be surmounted before there can be wide spread acceptance of this technology as a practical pipe rehabilitation method.

- Fold-and-Formed Liners – The fold and form process involves collapsing a liner into a "U" or "C" shape either in the manufacturing plant or on site. After insertion, typically using a winch, the liner is reverted to a "close fit" using air pressure and/or heat. For pressure pipe renovation, liners based on polyethylene (PE) are typically used. Insituform has developed a polyester fiber reinforced polyethylene (PRP) liner that can achieve a 150 psi independent pressure rating at a thickness of just a few millimeters. The product is factory folded into a "C" shape and transported to site on a reel.
- Bi-stable Reeled Composite Pipe/Liners – Wellstream, Inc. (Division of Halliburton Energy Services Group) has developed a prototype bi-stable reeled composite product offering the potential to make strong, lightweight, composite pipes and pipe linings. As the composite liner is unreeled it changes shape from a flat strip to an overlapping circular strip that can be pulled into position in the pipe or pipeline. The liner is referred to as bi-stable because it is reeled as a flat strip but deployed as an overlapping circular strip. Once the liner is deployed it is longitudinally seam welded on site using a containerized system. The adhesive for the Wellstream product is activated and cured using induction heating. One example of a cured 100 mm (4 in.) diameter pipe with a wall thickness of 2.5 mm (0.10 in.) is said to have a 60 bar (870 psi) short-term burst pressure.

## 4.0 Development Needs

### 4.1 Weld Repair Methods

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. 2000+ ft.), the ability to transverse bends and miters, 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.

### 4.2 Fiber-Reinforced Composite Repair Methods

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 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 will also need to be addressed.

## 5.0 Summary

Potentially applicable to gas transmission pipelines, two broad categories of inside repair technologies have been identified and reviewed: deposited weld metal repairs and fiber-reinforced composite repairs. Both are used to some extent for other applications and could be further developed for internal, local, structural repair of gas transmission pipelines.