



2009

The projects our members support result in intelligence and technology that address the needs of the worldwide pipeline industry and, by extension, global energy consumers.

YEAR IN REVIEW



our members

Working to assure the safe, reliable, environmentally-sound, and cost-effective pipeline transportation of energy to consumers worldwide.

PRCI PIPELINE MEMBERS

Alliance Pipeline Ltd. (Canada)
Boardwalk Pipelines
BP
Buckeye Partners, LP
CenterPoint Energy Gas Transmission
Chevron Pipe Line Company
Colonial Pipeline Company
Columbia Gas Transmission Corp.
ConocoPhillips Pipe Line Company
Dominion Transmission Corp.
El Paso Corporation
Enbridge Pipelines Inc. (Canada) &
Enbridge Energy Partners, LP
EPCO, Inc.
Explorer Pipeline Company
ExxonMobil Pipeline Company
Gassco A.S. (Norway)
Gasum Oy (Finland)
GDF Suez (France)
Marathon Pipe Line LLC
N.V. Nederlandse Gasunie (Netherlands)
National Fuel Gas Supply Corporation
National Grid (U.K.)
Pacific Gas & Electric Co.
Panhandle Energy Company
Petrobras (Brazil)
Saudi Aramco (Saudi Arabia)
Shell Pipeline Company LP
Southern California Gas Co.
Spectra Energy Transmission, LLC
Total S.A. (France)
TransCanada PipeLines, Ltd. (Canada)

TransGas Ltd. (Canada)
Transwestern Pipeline Co.
Williams Companies, Inc.

PRCI ASSOCIATE MEMBERS

Applus RTD
GE Oil & Gas
Lincoln Electric Company

PRCI TECHNICAL PROGRAM ASSOCIATE MEMBERS

Australian Pipeline Industry Association, Ltd.
Berg Steel Pipe Corporation
Cameron Compression
Dresser-Rand Corporation
Elster-Instromet N.V. (Belgium)
Evraz Inc. NA (Canada)
NDT Systems & Services (America) Inc.
Nippon Steel Corporation (Japan)
ROSEN USA, Inc.
Solar Turbines, Inc.
Sumitomo Metal Industries, Ltd. (Japan)
T.D. Williamson, Inc.
Tubos de Acero de Mexico, S.A.
Welspun Tubular LLC

PRCI PIPELINE INDUSTRY ORGANIZATIONS

Association of Oil Pipe Lines (AOPL)

Member list as of January 2010

“Pipeline Research Council International is the preeminent global collaborative research development organization of, by, and for the energy pipeline industry.”

—GEORGE W. TENLEY, JR. • PRESIDENT

2009

YEAR IN REVIEW

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MISSION

To conduct a collaboratively-funded research and development program that enables energy pipeline companies around the world to provide safe, reliable, environmentally compatible, and cost-efficient service to meet customer energy requirements.

PRCI'S VALUE PROPOSITION

PRCI leverages our members' resource contributions to create a research forum of ideas and results producing solutions that provide a spectrum of quantified benefits to the pipeline industry. Formal cost/benefit studies of member participation show a consistently positive ratio ranging from 4:1 to 7:1 from reduced costs of operations and maintenance, inspection, materials, design, construction, and testing.



Chairman's statement

PAUL F. MACGREGOR

As I believe this report on the achievements of PRCI in 2009 will demonstrate, this is an exciting and important time for research in support of the energy pipeline industry. In taking on the role of Chairman of PRCI for the next two years, I believe strongly that PRCI is positioned extremely well to enhance and diversify its leadership in energy pipeline research.

More than ever before, the energy pipeline industry will become a critical element in the ability of nations around the world to confront the large and complex issues they face in energy security, energy diversification, environmental performance, and infrastructure capability, integrity, and productivity. Not surprisingly, PRCI is engaged in each of these areas with a membership of 52 leading companies operating on five continents. Given the breadth and impact of these issues and challenges, the only realistic way to confront them, from a research perspective, is through the type of collaboration of pipeline operators and their stakeholders upon which PRCI has built its 57 years of success. During its history, including the very successful 2009 research program highlighted in this report, PRCI has developed a substantial portion of the underlying technology and research results that define every segment of pipeline operations from design to construction to operations and maintenance to testing and inspection. In addition, our efforts in the areas of compressor and pump stations, measurement, and underground storage have also served to assure pipeline system performance and reliability. Together our pipeline and facilities programs have been responsible for much of the innovation that has taken place in this very critical component of the energy value chain.

However, the state of research in support of energy pipelines is in a critical phase. This is due to the fact that the success of the collaborative model is dependent on the participation of the operating companies who comprise the industry. It is our pipeline industry members who are best able to define the needs of the industry, identify the research that best serves those needs, and oversee and implement the research that PRCI undertakes. Research for the energy pipeline industry can only be successful in serving its critical role for the industry if operating pipeline companies continue to bring their resources to the effort. I hope that those companies who currently are not members of PRCI will see in the achievements of our 2009 program the basis to consider membership in this remarkable organization. This industry will be constrained in meeting the challenges and opportunities it faces unless its commitment to research grows. That growth can occur best through collaboration and the leverage in the ideas, results, and resources it delivers. I think you will find our 2009 program contributed directly to those outcomes.

I hope you find this report to be of value to you as you consider the role of research in the overall success of your organization, and if you have any comments you would like to share with us, we would very much like to receive them.

Paul F. MacGregor
Chairman



President's statement

GEORGE W. TENLEY, JR.

In closing out one of the most successful years in its history, PRCI is positioning itself for 2010 and the range of issues, challenges, and opportunities the new year will inevitably bring. Certainly our future success in meeting the needs of our members and the pipeline industry worldwide will be well-served by all that we achieved in 2009. This report captures the research highlights of those achievements and illuminates the impact that collaborative research can have in enabling the energy pipeline industry to sustain and enhance its remarkable record of productivity as a critical element in the energy value chain.

Despite our success in 2009, a year which built on the 57 years of success that preceded it, we have continued to take the steps necessary to assure that the work we do and the research it produces continue to justify the investment of our members in the contribution of their funding and the technical knowledge and experience of the men and women who represent them in PRCI. One of the key measures of the value we deliver is the timeliness of our work in converting a good idea into the means to enhance system safety, reliability, environmental performance, and productivity. Building on our work in 2008 in our Research Deployment Optimization program, in 2009 we developed a research implementation and management system that clearly defines the roles, responsibilities, and accountabilities for all members of the collaborative PRCI team. This system, as augmented by our web-based research management tool, PRIME, enables the most cost effective engagement of our human resources while assuring that our members can be engaged in each step of our research process, whether in person or across our website.

The research engagements and results presented in this report demonstrate the breadth of our program and its direct relevance to the leading issues facing our membership, the industry at large, and nations around the world. Among the numerous and diverse research projects PRCI undertook in 2009, perhaps the best examples of the importance and impact of our research are the Emissions Reduction for Legacy Engines (ERLE) program and the Rights-of-Way Automated Monitoring (RAM) program. These two programs stand out not just because they address substantial and critical issues facing the industry (environmental performance and protection of the right-of-way, respectively), but they also demonstrate how otherwise separate, but topically-related, projects can be leveraged together to generate results of greater impact. These programs include a broad and diverse cross-section of our membership and they have garnered some of the largest funding commitments in our history.

I join our Chairman Paul MacGregor in encouraging pipeline companies who are not currently members of PRCI to strongly consider joining those leaders in the industry who have made the commitment to collaborative research through their participation in PRCI. In closing, let me pose several questions: *If not research, why? If not collaboratively, how? If not PRCI, who? And, if not now, when?*

A handwritten signature in black ink that reads "George W. Tenley, Jr." with a stylized flourish at the end.

George W. Tenley, Jr.
President

Broadening Research Collaboration to Meet the Challenges Facing the Energy Pipeline Industry

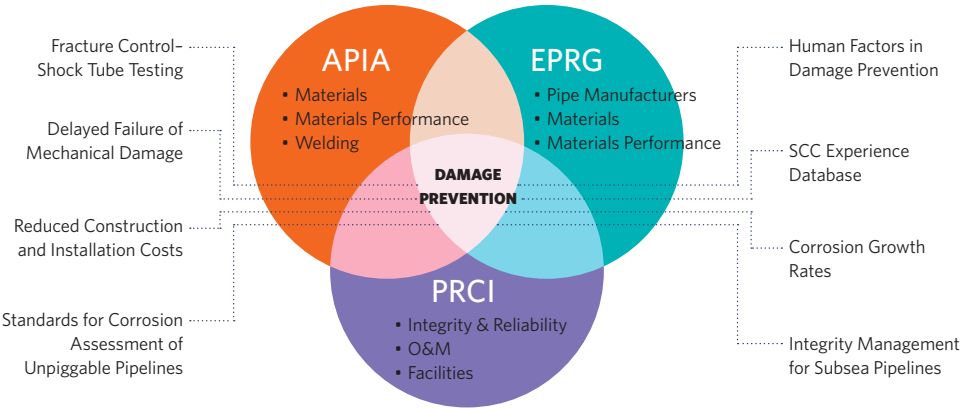
The 17th Biennial EPRG-PRCI-APIA Joint Technical Meeting on Pipeline Research

In terms of international reach, breadth of participants, and impact, one of the most significant collaborations in pipeline research is the one formed by the tripartite partnership of the European Pipeline Research Group (EPRG), the Australian Pipeline Industry Association (APIA), and PRCI, each of whom operates under its own collaborative, voluntary model. Together, the three organizations have 110 members operating on five continents, the majority of whom are pipeline operating companies. This pipeline membership is augmented by steel and pipe manufacturers, inspection tool and equipment manufacturers, engineering and construction firms, and field service providers.

Beginning 34 years ago as a bilateral relationship between EPRG and PRCI, the partnership was formally expanded in 2005 to a trilateral arrangement with the addition of APIA, operating through its Research and Standards Committee. The cornerstone of the partnership is a biennial joint technical meeting on pipeline research, the 17th of which was held in Milan, Italy in May 2009. The meeting was hosted by EPRG, and proved again that the JTM represents a world-class forum for pipeline research excellence and addressing the challenges confronting the pipeline industry at a global level. The JTM was well attended by representatives of all three participating organizations. Consistent with prior JTMs, there were a number of panels within topical areas where technical papers were presented by representatives of the member companies of the three organizations and our research contractors.

In addition to the technical papers, a primary focus of the meeting was a series of separate interactive workshops in parallel tracks that were organized by research program areas and technical disciplines to discuss and establish common research needs and identifying opportunities for collaboration. The objective of these sessions was to generate action plans for future research among the three organizations.

As an outcome of the discussions at the JTM, a technical proposal was developed for a collaborative research project that would be funded and include active participation by all three organizations. The project addresses time-delayed failure of Mechanical Damage defects, and complements related work already being performed by PRCI and EPRG. The project has received the support and has been funded for implementation by each of the tripartite member organizations, and will be initiated in early 2010. This is an important project that not only advances the body of knowledge on mechanical damage assessment, but will also demonstrate the commitment of PRCI to embrace our collaborative research agreement with our tripartite partners and take action to make it functional and meaningful.



Although well-established as a forum for the members to share recent and emerging research results, for the first time the Milan meeting set the course for direct research project interaction, funding, and management via the interactive workshops. As arrayed around the core capabilities of the tripartite relationship, the following are the key topics to be considered during the next biennium:

- ➔ Assessing the role and impact of human factors in damage to pipelines and damage prevention.
- ➔ The development of shock tube testing as a means for fracture control.
- ➔ Assessing and controlling the delayed failure phenomenon in mechanical damage.
- ➔ The development of a comprehensive database on stress corrosion cracking (SCC) experience.
- ➔ Development of new means to reduce construction and installation costs. [Note: In this work, the tripartite partnership will be expanded to include the International Pipe Line and Offshore Contractors Association (IPLOCA).]
- ➔ Development of standards on the assessment of corrosion on pipelines not suited for in-line inspection.
- ➔ Establishing the criteria for assessing, monitoring, and controlling corrosion growth rates.
- ➔ Developing the criteria and practices for the integrity management of subsea pipelines.

PRCI appreciates the participation and support of our member company representatives that were in attendance in Milan. PRCI looks forward to hosting the next Joint Technical Meeting in May 2011 in San Francisco.

Pipeline Hazardous Materials and Safety Administration (PHMSA) Research & Development Forum

In June 2009, the Pipeline Hazardous Materials and Safety Administration (PHMSA) of the Department of Transportation sponsored a Joint Government/Industry Research & Development (R&D) Forum in Washington DC. The R&D Forum provided the opportunity for collaboration between PHMSA and the pipeline industry on identifying the key challenges

facing the pipeline industry, and establishing meaningful and effective R&D programs to address those challenges. The meeting included a plenary session where various government (PHMSA, MMS, EPA) and industry (INGAA, AGA, API/AOPL) stakeholders, including PRCI member company representatives provided their perspectives on the industry R&D needs.

PRCI Chief Operating Officer Eric Thomas was a member of the Steering Committee that was assembled by PHMSA to develop the program for the R&D Forum, and a number of other PRCI staff and member company representatives played an active role in helping organize the meetings and leading and developing the Technical Tracks during the forum. The topics that were addressed in the Technical Track sessions have a direct relationship and relevance to PRCI's research programs, and the R&D gaps identified as an outcome of the forum are consistent with those identified through our programs and roadmaps.

PHMSA issued a Broad Agency Announcement (BAA) in November 2009 soliciting research proposals to address the identified gaps and PRCI is developing responses to the solicitation through partnerships with our research contractors and other external parties. Many of the topics identified as needing additional research are directly linked to ongoing PRCI research projects and programs, and we expect that several of the responses submitted will be favorably received by PHMSA and eventually be awarded R&D contracts. PRCI's participation in the R&D Forum and in responding to the BAA further advances our commitment as a primary partner with PHMSA in pipeline R&D.

Recent Accomplishments in Research

The projects members support with input, funding, time, and resources result in intelligence and technology that address the needs of the worldwide pipeline industry and, by extension, global energy consumers. PRCI focuses on projects that:

- Assure system safety and environmental performance
- Assure the productivity and reliability of pipeline assets
- Anticipate change and adapt existing systems
- Allow our members to build new pipelines where and when they are needed
- Continue to reduce risks from and to pipelines
- Provide support for public policy positions

Research Reports

CORROSION

- Augmenting MFL Tools with Sensors that Assess Coating Condition
- Corrosion Assessment Guidance for High Strength Steels (Phase 2)
- Define Operating Conditions in which Internal Corrosion is Extremely Unlikely to Exist
- Detailed Procedures for Comparing Successive ILI Runs to Establish Corrosion Growth
- Guidelines for Reliability-based Pipeline Integrity Methods
- Leak vs. Rupture Boundary for Pipes with a Focus on Low Toughness and/or Ductility
- Remaining Strength of Corroded Pipe Under Biaxial Loading
- SCC in Areas of Local Deformation
- Validation of Predictive Methodologies for Cyclic Loading Conditions

DESIGN, MATERIALS & CONSTRUCTION

- Acoustic Source Level and Signature Measurement of Pipeline Scratches and Gouges
- Develop Criteria/Guidelines for Welding on In-service Chemical Pipelines
- Development of Techniques to Assess the Long-term (Post Formation) Integrity of Wrinkled Pipeline Segments - Phase 2
- Effects of Static & Cyclic Loads on Vintage Welds
- Guidelines for Safe Inspection and Repair of Mechanical Damage Defects
- Model for Predicting the Likelihood and Severity of Newly Created Damage
- Pipeline Integrity Management for Ground Movement Hazards
- Reliability-based Design and Assessment of Onshore Gas Pipelines
- Update API RP 1111, Third Edition, Dated July 1999
- Vintage Girth Weld Defect Assessment - Comprehensive Study

OPERATIONS & INTEGRITY

- Conceptual Pipeline Integrity & Security Management
- Measuring the Effectiveness of Current ROW Monitoring Techniques/Practices

- Performance Characteristics of Current In-line Inspection Technologies for Mechanical Damage Detection
- Small Leak Detection in Liquid Pipelines — External Leak Detection Evaluation and Development
- Technologies for In-service Measurement of Seal Gaps in Internal Floating Roof Tanks

COMPRESSOR & PUMP STATION

- Alternatives to Gas Expansion Starters
- Comparison of NO₂ Measurement Techniques for Lean Burn Exhaust
- Compressor & Pump Station Incidents and Technology Gaps
- Development and Prototyping of a Variable Geometry Turbocharger
- Development of an Active Air Control System
- Evaluation of Byproduct Emissions from Gas Turbine SCR Catalyst
- Evaluation of NO_x Sensors for Control of Exhaust Aftertreatment Systems
- Exhaust Manifold Design Guidelines
- Increase the Efficient Operating Range of Centrifugal Pumps
- NO₂/NO_x Ratio from Lean-Burn Natural Gas Engines
- Pre-combustion Chamber Development and Laboratory Testing
- Reciprocating Engine Diagnostics White Paper

MEASUREMENT

- Assessment of Dirty Meter Performance
- Flow Measurement with Low Differential Pressure
- Gas Sampling at Hydrocarbon Dew Point Conditions
- Investigate MEMS Technology for Application to Gas/Liquid Quality Measurement (Phases I & II)
- Lower-Cost Liquid Meter Prover Calibration Method
- Measurement Flow Library (web-based)
- Ultrasonic Meter Diagnostics for “Smart Ultrasonic Meter” Development
- Ultrasonic Meter Recalibration Intervals

UNDERGROUND STORAGE

- Brine String Integrity Survey & Model Evaluation
- Predicting and Mitigating Salt Precipitation (Phase II)
- Smart Gas: Using Chemicals to Improve Gas Deliverability (Phase II)

Important Findings

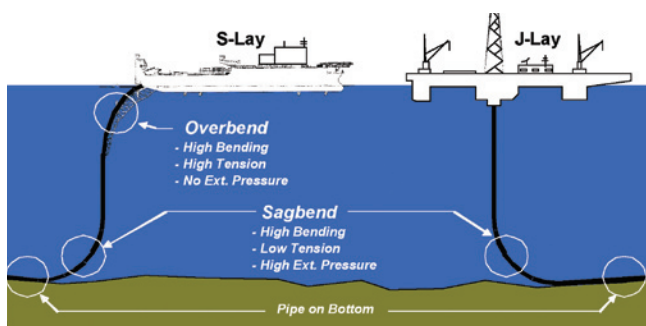
PRCI’s research projects have produced numerous important findings that our members are able to put into practice resulting in cost efficiencies, operational changes, and evaluation programs. Some of the most recent are as follows, a select set of which are described in further detail in the accompanying appendix:

CORROSION

- Development of a “User’s Guide” to assist operating companies to successfully select, implement, and validate methods for determining corrosion growth rates using data from successive in-line inspection (ILI) runs. Validation of the User’s Guide showed that a key issue addressed in this process is the effect of measurement uncertainty of the ILI technologies on growth rate calculations, which is addressed using probability distributions for sizing anomalies. The methodology developed allows for estimates of corrosion growth rates for individual anomalies using either defect or signal matching techniques, and segment matching techniques for inferences on the entire defect population within a given pipeline segment.
- Completed a multi-year research study that resulted in the development of practical guidelines for evaluating the threat for internal corrosion in dry natural gas pipelines. The guidelines provide pipeline operators with a tool for determining the likelihood of an internal corrosion threat for given operating conditions, and provide a basis for adjusting operating conditions to minimize or control the threat. The guidelines provide an alternative to other methods of internal corrosion threat assessment, such as in-line inspection, hydrostatic pressure testing, and Direct Assessment. The model was developed using relatively simplistic operating charts and an Excel spreadsheet macro/tool.
- Established the methodology for reliability-based corrosion integrity management for external corrosion. The comprehensive reliability-based approach forms the basis for an industry-accepted approach to assessing pipeline integrity and quantifying the benefit and value of inspection and repair. After validating the methodology for external corrosion, this process may be adapted to all time-dependent damage mechanisms.
- Formulated a methodology to determine the leak versus rupture boundary for pipe-body corrosion and evaluated the boundary conditions in regard to material toughness and ductility. This work provides for reliably discriminating between conditions that lead to leaks and ruptures and is important in prioritizing maintenance and other aspects of integrity management.

DESIGN, MATERIALS & CONSTRUCTION

- Developed an interpretation and application guidance document for API Standard 1104 — Welding of Pipelines and Related Facilities. This document will reduce the variance in weld quality and possibly avoid unnecessary costs and time resulting from variance in interpretation of API 1104 by both operators and regulators.
- Developed recommendations for enhancing the design methodology described in API Recommended Practice 1111 for the Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines. These enhancements involve the use of strain-based design for selected transportation, installation, and operation load cases.
- Building on prior research to support in-service repair and hot-tap welding, one project developed a comparable approach for the chemical pipeline industry. Safe and efficient in-service welding of chemical pipelines reduces operating costs by avoiding pipeline shutdowns for maintenance/repair welding. This research provides the basis for safe, in-service welding applications throughout the chemical industry.
- The Pipeline Integrity Management For Ground Movement Hazards project resulted in the development of guidelines for constructing natural gas and liquid hydrocarbon pipelines



J-lay and S-lay Installation Methods. Figure illustrates the bending locations during S-lay and J-lay installations. Strain-based limit states for this load case: ovalization, local buckling, and tensile fracture.

Source: DeGeer, D. & Nessim, M. (2009). Using Strain-based Design in Conjunction with API RP 1111.

through areas prone to landslide and subsidence hazards, providing the following benefits:

- Establishes systematic approach, illustrated with detailed flow charts, for managing pipeline risks from landslide and subsidence hazards.
- Defines a common framework for pipeline operators, the local, state, and federal agencies that have regulatory oversight, and the general public to engage in discussions regarding potential risks from pipelines in areas of unstable ground.
- Recommends methods to reduce the severity of the hazard through site modifications, pipeline design and operational measures, and vigilance through routine monitoring.
- Defines improved methods for analyzing pipeline response to ground displacement and enabling selection of appropriate combination of mitigation measures.
- Presents methodology to determine both bending and axial strains in pipelines from ground displacement using geometry measurements made by advanced in-line inspection tools.

OPERATIONS & INTEGRITY

- Completed a comprehensive evaluation of a wide range of external leak detection systems and technologies for liquid pipelines. This work narrowed down the technologies to two approaches that will be evaluated further through laboratory testing in the coming year. Preventing loss of product via small leaks has substantial impact by reducing effects on the environment and related cost for remediation and public perception. Full development and implementation may take several years.
- Identified the elements and criteria that make a pipeline unpiggable through a comprehensive review of existing literature and standards, including onshore and offshore pipelines. Improved understanding of these criteria will lead to improved approaches to integrity management planning and implementation, pipeline design, and development of new technologies for pipeline inspection.
- Confirmed the effectiveness of pipeline damage prevention efforts through use of the One-Call system, with over 99% effectiveness. Statistics also showed that most incidents (i.e., hits or near misses to pipelines) occur when no one-call is made. The results demonstrate the need for continued diligence and advocacy for Public Awareness on the presence of operating pipelines.
- Completed the initial phase of an assessment to confirm the performance of EMAT ILI tools for detection, identification, and characterization of SCC, including the development of a methodology for evaluating EMAT results that includes comparison to field inspection/excavation data and hydrotest results. The results confirm progressive improvements of the technology, though additional advancements are required.
- Conducted a performance evaluation of current technologies for detection and

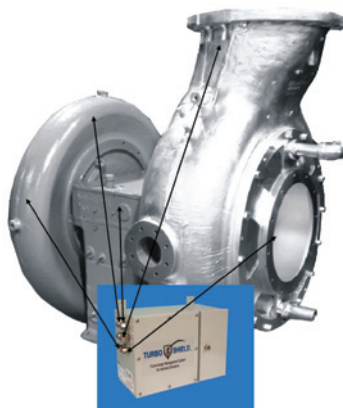
RECENT ACCOMPLISHMENTS IN RESEARCH > CONTINUED

discrimination of mechanical damage using improved in-ditch tools, and developed a protocol for in-ditch mechanical damage characterization to minimize field measurement errors. The procedures developed build on operator best practices and incorporate the latest technology advancements, and are currently being qualified through inspection and measurement of actual mechanical damage defects and anomalies in the field.

- Completed Phase 2 of a comprehensive evaluation of the performance capabilities of current ILI technologies to detect and discriminate mechanical damage to pipeline systems. The Phase 2 study resulted in improved statistical measures for ILI technologies and further validation of technology performance using ILI data and field inspection data provided by pipeline operators.

COMPRESSOR & PUMP STATION

- Commercial introduction of the TURBOSHIELD™ turbocharger monitoring system by Exterran Holdings, owner of the largest fleet of compression equipment in North America. This is the result of a 2006 PRCI project at Kansas State University to develop a system to monitor and trend turbocharger performance. As pipeline engines are forced to comply with more restrictive air permits, their margin of permit compliance continues to narrow, and TURBOSHIELD™ provides the ability to track in real-time whether the turbocharger is maintaining its design performance and is providing combustion air flow adequate to achieve the very lean air/fuel ratios necessary for low-NOx operation.



Source: Exterran Holdings

- A novel method that employs a spark plug to determine the chemical and thermal environment within an engine cylinder, termed “ion sense,” has been installed on a set of early adopter engines by Hoerbiger Corporation. Ion sense can detect combustion pressures and temperatures very accurately and with little drift, and is employed on engines to enable any number of control and monitoring capabilities, from closed-loop autobalancing, to detecting misfire, to monitoring the conditions within a pre-combustion chamber. Ion sense is tied back through an Altronic ignition system, and has the promise of being robust and relatively inexpensive, yet is an enabling technology for a variety of advanced engine control concepts for low-emissions operation.

MEASUREMENT

- Correlated the contamination level of dirt buildup inside an ultrasonic meter and surrounding pipe to the measurement error. Ultrasonic meters proved to have a potential for providing diagnostic information that can be used to assess the meter condition. By characterizing meter error as a function of contamination level and by utilizing auxiliary measurements provided by the ultrasonic meter to detect contamination, maintenance practices, and measurement accuracy can be improved.
- Evaluated the performance of multiple types of transmitters in various size orifice meter runs at low differential pressures (DPs), simulating low flow transmission meter stations and depleted production well stations. The results were analyzed to characterize and

better understand the uncertainties and measurement errors associated with orifice meters operating with small bore diameters and low DPs.

- Established a web-based searchable database of over 50,000 documents related to Gas Measurement. These papers and reports include original research works, conference proceedings, and materials from individual collections of long-term gas industry measurement experts/consultants. PRCI members are able to download many of these documents directly, while other documents have complete bibliographic references that directs the user (via weblinks) to the separate sponsoring organization so that the work can be obtained from that originating source.

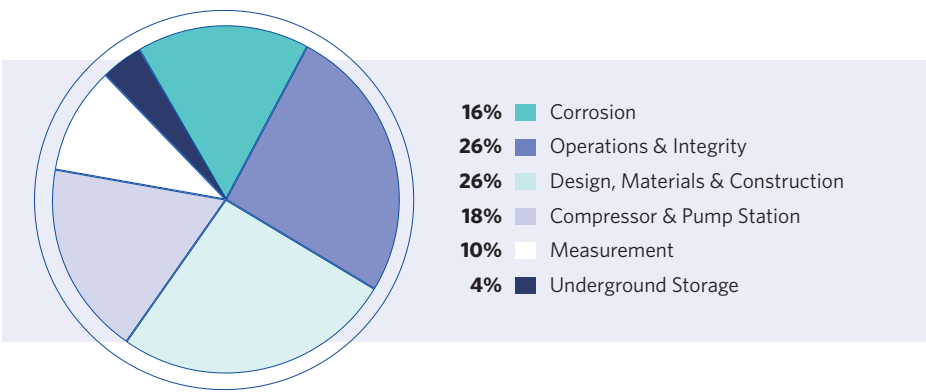
UNDERGROUND STORAGE

- Investigated the application of a cost-effective and practicable set of chemicals to reduce salt precipitation in salt cavern underground storage facilities. The project focused on determining the concentration of active inhibitors required to inhibit salt deposition, the environmental impact of using the inhibitors in the field, and the chemicals potential in salt caverns through an analytical approach.
- A salt cavern brine string integrity survey & model evaluation uncovered significant shortcomings in existing modeling methods and concluded that the current analytic framework for avoiding brine string failures, which has generally focused on limiting flow velocity, should be more conservative and cannot explain some failures.

Current Research

Every year, PRCI produces a collaborative research program aligning with the industry's priorities by means of an annual voting ballot. Members allocate funds directly to programs of importance to their operations and business drivers. The funding for this research is further augmented by member company supplemental contributions and cofunding from non-member companies. Following are some highlights of our current program focus, and related projects.

Last Five Years • 2006–2010 Research Programs • Member Funding Distribution



Corrosion

- ➔ Analyzing the performance of available technologies for identifying and characterizing external corrosion on pipelines. The analysis of technologies includes both ILI tools and field methods and measurement systems, and the correlation between the two data sets to measure performance capabilities (POD, POI, etc.).
- ➔ Developing alternative methods and validating techniques for inspecting cased piping where test facilities are not available, and evaluating innovative approaches to applying long-range guided wave technology using advanced modeling methods to improve inspection and characterization of corrosion on cased pipe.
- ➔ Evaluating the performance of coatings, including the performance of coatings common to older, vintage pipelines and newer coatings technologies that may provide opportunities to operate at increased design factors.
- ➔ Finalizing the technical evaluations for a consolidated program to assess the remaining strength of corroded pipelines, a multi-year comprehensive effort conducted in partnership with PHMSA since 2005. The consolidated program consists of six separate projects, including a comprehensive Guidance Document for corrosion assessment, which is scheduled for completion in early 2010 and will provide a compilation of all the project test results for practical application of the research findings. PRCI is well-positioned to continue this work in 2010, with a project award expected from PHMSA for an extension to the current program for additional burst testing and analysis of remaining strength assessment methods for higher strength steels to fill a key gap from the prior work.
- ➔ A program to determine the susceptibility of operating pipeline systems to the formation

and growth of Stress Corrosion Cracking (SCC) and fatigue cracking, and the factors and conditions that lead to crack dormancy. Guidance is also being developed for SCC Direct Assessment (DA) and re-inspection intervals, which is expected to support modifications to industry standards. Analysis is based on environmental and operating data from pipeline operating companies.

- Advancing the program on developing a methodology and guidelines for assessing pipeline integrity with respect to corrosion over time using reliability-based methods. In 2009 the program focused on validating the guidelines developed and completing a study on comparing successive ILI runs to establish corrosion growth rate, a key parameter for the reliability-based approach. A supplemental project was added to the program (via the 2010 ballot) to compare probabilistic methods against reliability-based methods and analysis.
- Continuing research on developing the best approach to manage the potential for internal stress corrosion cracking (SCC) to occur while transporting fuel grade ethanol. The PRCI SCC-4 program “Ethanol Transportation in Pipelines” began in 2007 and will culminate in 2012 with the completion of SCC-4-5. The research has indicated that a 10% mixture of ethanol in gasoline (E10) can be transported without any modification to the existing transportation system.
- Multi-year ethanol research program with emphasis on identifying environmental and stress factors that produce SCC in existing pipelines and terminals, developing requirements for existing pipeline, tank and terminal systems to transport ethanol without cracking and identifying the requirements and developing design criteria/guidelines for new pipeline systems to transport ethanol without cracking.

Design, Materials and Construction

- Continuing program to develop a safe and viable alternative to the pre-service hydrotest of natural gas pipelines. This could result in significant time and cost savings especially for pipelines in Arctic areas.
- New program to identify the tools for evaluating the integrity of vintage (pre-1970) girth welds, and the typical characteristics and properties of these welds. This work will identify gaps in prior studies to guide research needed for a comprehensive approach for evaluating in-service vintage girth welds.
- Work continues in the assessment of composite repair systems. One ongoing project is assessing the availability, variety and long term performance of composite pipeline repair systems. The other is evaluating composite materials for reinforcing mechanically-damaged pipelines.
- Research and development in the welding high strength steel pipelines remains a high priority. The objectives are to develop a fundamental understanding of factors that affect the mechanical properties of these welds as influenced by welding parameters and to develop optimized solutions. This multi year program continues in 2009, jointly funded with DOT, with an estimated completion date of 2010.
- PRCI continued its multi-year commitment to a comprehensive and consolidated program to evaluate the structural significance of mechanical damage. Work in 2009 was directed toward the creation of realistic mechanical damage features and the performance of a series of burst and fatigue tests to evaluate the impacts of mechanical damage particularly in terms of severity on operating pipeline systems. These highly instrumented tests are providing the data needed for improving current burst and fatigue failure models. Testing has included plain dents

and dents with secondary features, including gouges, corrosion, and welds. PRCI members contributed over \$600,000 in additional funding to the program in 2009, including a coordinated project with our partner organizations APIA and EPRG for the delayed failure of mechanical damage under constant pressure loading. This program is also supported by and being conducted in partnership with PHMSA through its R&D program.

Operations & Integrity

- ➔ Continuing research to develop step-change technology for monitoring and surveillance of pipeline systems through the comprehensive Right-of-Way Automated Monitoring Program, or RAM. The RAM Program includes developing integrated sensing suites and algorithms for processing data to provide safer, smarter, and more cost-effective aerial surveillance for threat detection, change detection, and leak detection. This program is being conducted in coordination with our research partners, NASA and PHMSA. Research was also conducted to evaluate the effectiveness of current techniques and practices that are focused on threat detection and damage prevention for third party unauthorized excavations and encroachments.
- ➔ Several technology development projects for understanding and improving the pipeline industry's capabilities to detect and characterize mechanical damage defects, including continued development of the dual-field Magnetic Flux Leakage (MFL) ILI technology, and developing and qualifying consistent methods and innovative tools for field inspection and measurement/characterization of mechanical damage features. In addition, PRCI is performing a comprehensive evaluation to better understand the MFL signals produced by mechanical damage in collaboration with PHMSA.
- ➔ Developing new tools and analytical methods for Non-destructive Evaluation of SCC in pipeline systems, including development and demonstration of an integrated tool for mapping, sizing and evaluation of SCC for remaining strength prediction, compiling data from ILI tool runs in operating pipelines, and performing statistical analysis to confirm the performance of Electromagnetic Acoustic Technology (EMAT) for SCC inspection and detection.
- ➔ Conducting a detailed performance capabilities study of current and emerging technologies for detecting fatigue cracks in heavy wall Steel Catenary Risers (SCRs) and piping used in offshore applications.
- ➔ Performing multi-phased comprehensive program to develop a Base Resource Document (BRD) for Unpiggable Pipelines, exploring existing methodologies to monitor and assess the status of unpiggable pipelines. Unpiggable pipelines are often only a small fraction of the mileage for any operator, but may represent a large portion of the risk profile. The program establishes the current state-of-the-art document detailing how to inspect, monitor, and manage unpiggable pipelines for onshore and offshore systems. The BRD will provide operators with better tools to assess and monitor pipelines to optimize resources and ensure compliance, and identify the gaps to establish where further research and technology development is required.
- ➔ The pipeline industry continues to be challenged by damage incidents caused by work on the pipeline infrastructure by first, second, and third parties operating in the common right-of-way. The Influence of Human Factors on Pipeline Damage Prevention project is aimed at identifying the human factor elements associated with first, second, and third parties that contribute to the damage statistics, and identifying practical methods to manage their adverse affects on the effectiveness of damage prevention measures.

Compressor & Pump Station

- Work continues on the multiple technical dimensions central to reducing reciprocating engine NOx in a cost-effective manner. The Emissions Control for Legacy Reciprocating Engines program continues with 2010 as the final year of the effort, culminating with two two-cycle field test engines being outfitted with a variety of the NOx reduction technologies that have been developed in the program. The seemingly continual tightening of NOx regulations has continued into 2009, with indications that widespread engine retrofits will be required from 2013 through 2017. Emphasis is now shifting to rich-burn engines, and the troublesome NSCR systems are the prescriptive rich-burn control technology. The evaluation of these systems is being broken into their air/fuel ratio sensor, controller, and catalyst elements in an attempt to isolate which components need additional development effort for the unique exhaust of natural gas. Promising early phase NSCR configurations are being tested. The vast body of catalyst work in the automotive industry has been for liquid-fueled vehicles that are in very intermittent operation, while NSCR has not yet been optimized for stationary, natural gas engines.
- General Electric is initiating work to evaluate whether improved lean-head-end liners can be developed for GE Frame 32 Gas Turbine Models A through F, providing incremental, but highly cost-effective, NOx reduction.
- Efforts to identify a host site continue for a project that will increase the part-load fuel efficiency of Solar Turbine units. This would enable a flattening of the engine fuel consumption across the load range and provide appreciable cumulative fuel savings for engines that are forced to operate at part-load.
- Develop the methodology and procedures to determine the remaining life of combustion turbine disks, thus avoiding expensive overly-conservative fired-hour based replacements. The focus of the first year of this work will be to link the proper analytic procedures to engine operating histories.
- Investigate the use of variable speed drives, viable frequency couplers, and alternative technologies for reduced power consumption at pipeline pump stations. The study will



Clockwise from above: 1. Cooper-Bessemer 16-W330, Station 40, Natchitoches, TX, El Paso; 2. Clark TCVC-20M, Sandwich Station, ANR Pipeline (TransCanada); 3. Newberry Springs , Southern California Gas Company (Sempra Energy)

Source: Advanced Engine Technologies Corporation.

determine which of the speed control drive technologies are best suited for the pipeline pump application, considering installation, maintenance, and operational costs/issues.

- Identify the facilities and costs associated with the development and construction of a pump test facility for high flow and viscous fluids. Potential locations for construction and operation cost of this facility will be identified along with potential co-funders.
- Summarize current practices and identify the latest technology and best practices for pump shaft sealing and seal leak detection systems to minimize the potential for an uncontained spill and resulting environmental incident. It is anticipated that results will complement/supplement existing requirements in API Standard 682 - Shaft Sealing Systems for Centrifugal Pumps - Third Edition.
- Determine reasons and strategies to address the three most critical causes or reportable incidents in compressor stations and the three most critical causes in pump stations.
- Investigate the issues of ethanol on pump station facilities with the focus on material compatibility on such items as: pumps, valves, piping, seals, and instrumentation.

Measurement

- Investigate whether it is possible to replace a mechanical prover by a viscosity-independent ultrasonic flow meter.
- Develop a Research Compendium — information would be gathered via literature searches, solicitations of industry members for non-proprietary and proprietary research material, and review of prior JIP's.
- Performance verification of perforated plate flow conditioners installed upstream of multipath ultrasonic meters and validation of AGA-9.
- Characterize the uncertainties and measurement errors associated with orifice meters operating with small beta ratios and low differential pressures.
- Determine the effect of build-up and wear on the performance of plate-type flow conditioners and quantify the magnitude of the flow measurement bias errors produced by the various types of flow conditioner wear or contamination.
- Determine the impact of high pressure calibration on measurement uncertainty for differential pressure transmitters by comparing calibrations completed at atmospheric pressure and several elevated pressure.
- Evaluate the uncertainty components of terminal measurement of LNG cargos to determine if current practice enables systematic error to propagate throughout LNG facilities.

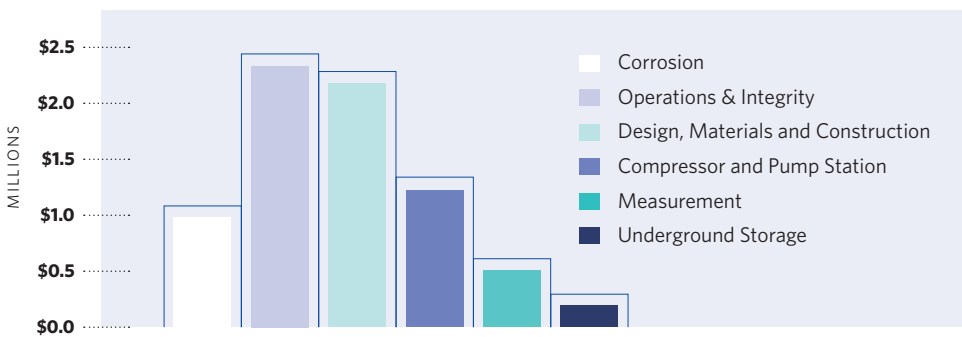
Underground Storage

- Determine whether brine strings can be properly stabilized to enable increased fluid velocity, via an extended full-scale field test of brine string stiffener concepts at an abandoned salt cavern in Texas.
- Evaluate the performance of high-resolution MFL inspection tools designed specifically for gas storage wells. This is being done with abandoned pipe that has been logged, then evaluated using the GRI RSTRENG model, and then burst test.

The 2010 Research Program

Key topical areas for the 2010 program include pipeline corrosion, integrity, operations, design, materials, construction, and facilities. The funding for the 2010 program contributes to a total research program exceeding US\$20 million.

2010 Research Program • Member Funding



In addition to core programs, the following highlights a number of initiatives in 2010 that will advance the energy pipeline industry through research, several of which are being undertaken with our European and Australian research partners:

- An assessment of research needs for CO₂ transportation in pipelines is underway as part of the international response to interest in managing CO₂ emissions from industrial activity. This work will identify the concerns associated with the transportation of CO₂ in existing pipelines and design considerations for new CO₂ pipelines. The result will be a coordinated research plan to address the specific technical issues associated with CO₂ transport.
- Guidelines are being developed to assist operators in evaluating damage to subsea pipelines.
- Research is beginning to field validate surface loading stress calculations for buried pipelines.
- Improved methods are being sought for estimating remaining fatigue life of ERW pipelines.
- Continued focus on determining the effects of mechanical damage to pipelines, including further development of databases and models for assessing the structural significance of mechanical damage and development of technologies and protocols for inspection to detect and characterize mechanical damage.
- Research focused on pipeline Damage Prevention, including the development of sensing technologies for monitoring and surveillance of existing rights-of-way corridors from aerial platforms and identifying promising technologies for preventing damage to subsurface structures during drilling operations. Detailed analysis of Human Factors that relate to Damage Prevention is also being conducted.
- Building on the initial literature review in 2009, a comprehensive approach for management of unpiggable pipelines will be pursued, including expanding the Base Resource Document to provide guidance for inspection and assessment of unpiggable pipelines.
- Improving the understanding of the effects of measurement uncertainty associated with standard pipeline inspection technologies. This research is linked to ongoing work on

Reliability-based Integrity Management and will lead to the development of standardized approaches for measuring the performance of pipeline inspection technologies and development of correction factors that account for uncertainties.

- Analysis and development of non-destructive evaluation (NDE) methods and technologies. 2010 focus areas include development of an integrated pipeline cleaning and inspection tool that will provide data collection capabilities during standard pipeline cleaning operations, and establishing clear benchmarks of performance for Long Range Guided Wave Ultrasonic technology.
- The development of cost-effective NOx controls for reciprocating compressor engines will culminate in field tests of promising technologies for lean-burn engines, and transition to a focus on after-treatment technologies such as catalyst controls for rich-burn engines.
- New greenhouse gas reporting regulations have spurred projects to re-examine standard emissions factors for compressor station fugitive emissions and to develop improved fugitives measurement methods and reporting procedures.
- Improved compressor and pump station facility integrity is being targeted by projects to evaluate the effects of vibration on station piping components, and improve the methods and practices used for bolted joints.
- The stability of brine strings in underground salt caverns is a limiting factor for integrity and deliverability. Brine string stiffeners will be evaluated for their potential to increase the allowable fluid velocities used for injection and withdrawal cycles.
- An extensive web-based measurement flow library will be introduced to enable pipeline operators to directly access research results, conference presentations, seminal technical documents and a large variety of information supporting technical standards.
- Ultrasonic gas meter operation under non-ideal conditions will be examined, including the effects of liquids contamination and situations where upstream piping is rather complex.

The 2010 Research Program will contribute directly to the issues facing the membership and the industry worldwide as it pursues projects in areas related to climate change, enabling the existing and new infrastructure to take on non-traditional energy supplies, the impending expansion of the pipeline infrastructure to meet new demands and changing markets and new supplies, and securing rights-of-way from intrusion and damages it can cause. One feature of the 2010 program that holds great promise for the future is the opportunity to bring related projects together into more comprehensive outcomes. This is another type of leveraging, and leveraging is a cornerstone of how we accomplish our mission.

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Pipeline Integrity Management for Ground Movement Hazards

The objective of ENV-1 “Pipeline Integrity Management for Ground Movement Hazards” was to develop guidelines and recommended practices for designing and operating pipelines in areas subjected to large-scale ground movements (landslides and subsidence).

The guidelines developed under the research project have produced several benefits. The most significant benefit is related to the systematic approach developed for managing pipeline risks from landslide and subsidence hazards. It is hoped that this approach, presented in detailed flow charts in the final report, will lead to improvements in current practices by providing a common framework for pipeline operators, the local, state, and federal agencies that have regulatory oversight, and the general public to engage in discussions regarding potential risks from pipelines in areas of unstable ground. This common framework is based upon an understanding of the uncertainty in predicting potential ground displacements, methods to reduce the severity of the hazard through site modifications, pipeline design and operational measures, and vigilance through routine monitoring.

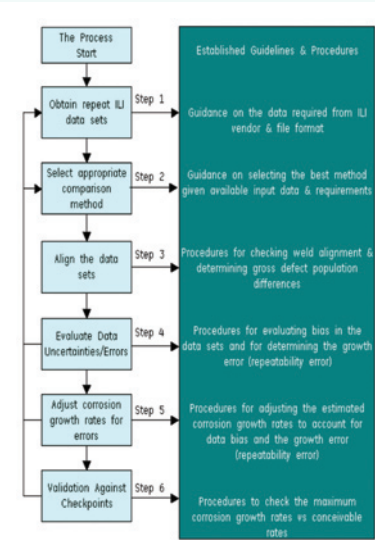
KEY PROJECT RESULTS

Experimental research conducted in this project resulted in new relationships for quantifying pipeline-soil interaction. Recommendations for analyzing pipeline response to ground displacements in the guidelines incorporate these new relationships as well as recent findings from other researchers. Improvements in analyzing pipeline response to ground displacement improve the ability to determine the appropriate balance between mitigation through pipeline design, geotechnical improvements, or operational measures.

The project also developed an algorithm to determine both bending and axial strains in pipelines from ground displacement using geometry measurements made by advanced in-line inspection tools. This represents an improvement over current methods that address only bending strain. The algorithm is appropriate for cases where there is some curvature in the pipeline caused by ground displacement. Based upon comparisons with a large number of simulated test cases, the accuracy of the axial strain using the algorithm is within ±20%. This level of accuracy is quite good considering the algorithm is independent of the properties of the pipe and surrounding soil and the characteristics of the ground displacement. As the algorithm is computationally straightforward, the axial strain algorithm can be easily programmed into existing in-line inspection tool software.

Source: Doug Honegger, DGH Consulting

Development of Detailed Procedures for Comparing Successive ILI Runs to Establish Corrosion Growth Rates



Overview of Process and Guidelines/Procedures Developed.

Source: Dawson, S.J., Wharf, J. & Nessim, M. (2009). Development of Detailed Procedures for Comparing Successive ILI Runs to Establish Corrosion Growth Rates.

The ability to accurately determine the rate of corrosion growth along a pipeline is an essential input into a number of key integrity management decisions. For example, corrosion rates are needed to predict pipeline reliability (probability of failure and/or probability of exceedance) as a function of time, to identify the need for and timing of field investigations and/or repairs and to determine optimum re-inspection intervals to name just a few applications. As more and more pipelines are now being inspected using intelligent in-line inspection (ILI) tools for a second or even third or fourth time, pipeline operators require reliable guidelines for comparing repeat ILI data sets to obtain valid corrosion growth rates. There is presently no industry guidance on how to perform such data comparisons, which can demand significant effort and expertise to ensure accurate and meaningful correlations between often very large data sets. This effort aimed at developing such guidance. Two main corrosion growth rate calculation methods are typically used in the industry: local growth rate estimation and segment growth rate estimation.

The project developed a guideline to assist operating companies to successfully select, implement and validate pipeline data-specific methods for determining corrosion growth rates using data from successive in-line inspection runs. The guideline sets out a six-step process for determining corrosion growth rates from repeat ILI data using these two approaches in an easy to follow and implement step-by-step format. A key issue addressed in this process is the effect of measurement uncertainty on growth rate calculations.

Practical Guidelines for Internal Corrosion Threat in Dry Natural Gas Pipelines

Internal corrosion threat in dry gas pipelines is low due to very low water content that is controlled under a tariff limit. However, the threat may exist when liquid water is brought into the pipe by condensation, intrusion from laterals, or via hydrotest. The threat can be confirmed through methods including in-line inspection, pressure testing, or direct assessment; however, each method has its limitations and is costly. It is important that methods be developed to identify and prioritize the likely locations of internal corrosion threat. Equally important are methods that can be developed to determine locations where an internal corrosion threat is extremely unlikely and thus inspections could otherwise be exempted or the reassessment interval extended. The goal of this work was to develop practical tools to determine the likelihood of internal corrosion threat for given operating conditions. With these tools an operator would be able to evaluate whether the current operation of its pipeline has an internal corrosion threat that is extremely unlikely or how to adjust its operation to control the internal corrosion threat to become extremely unlikely. By having a quantitative understanding of the level of internal corrosion threat, the operator may be able to present a convincing case to regulators that allows for extending the reassessment interval of in-line inspection, pressure testing, or direct assessment.

KEY PROJECT RESULTS

The level of an internal corrosion threat depends on the time duration that the pipe surface is wet and on the magnitude of the corrosion rate. The time that a pipe is wet by water condensation depends highly on temperature (mean and seasonal amplitude) for a given operating pressure. The higher the temperature, the lower is the probability of water condensation. Meanwhile, the higher is the corrosion rate in the presence of water. However, it is the probability of water condensation that predominantly determines the wall loss or internal corrosion threat. For the above reason, the greatest internal corrosion threat by water condensation is located downstream from a compressor station where the temperature is lowest. A higher fluctuation of seasonal temperature further increases the internal corrosion threat. The former is highly dependent on the geographical location of a pipe section. For a water content controlled under the tariff limit, the probability of internal corrosion threat is very low when the operating pressure remains below 1200psi and the operating temperature mean is greater than 50°F.

The Assessment of Corrosion Damage in Pipelines Subjected to Cyclic Pressure Loading

A range of methods exists for assessing the remaining strength of a corroded pipeline under static pressure loading and these have now matured to the extent that they are incorporated in regulations and standards. However, there is currently no guidance for assessing the performance of a corroded pipeline under cyclic pressure loading. This is of potential concern to operators where there are significant pressure variations. It is possible that a corrosion defect could be assessed as acceptable for the maximum operating pressure of a pipeline, but fail by fatigue due to internal pressure fluctuations. This project was conducted to develop an assessment method for pipelines containing corrosion defects which are subject to fluctuating pressure loadings. The method involves estimating the stress raising effect of the corrosion defect to determine the enhanced cyclic stress range associated with the feature. This stress range is then used with a stress – life (S-N) curve to derive the fatigue life of the corrosion defect. This life can then be used to determine if the defect is acceptable, or the time until a repair is required.



Test 2 Vessel After Rupture.

Source: Liu, J., Mortimer, L. & Wood, A. (2009). Corrosion Assessment Guidance for High Strength Steels (Phase 2).

KEY PROJECT RESULTS

The work completed resulted in development of a method for assessing the life of volumetric corrosion defects under cyclic loading. The method is based on determining the stress raising effect of the corrosion defect combined with a S-N curve for parent plate material in a corrosive environment. A wide range of defect geometries were analyzed to determine elastic stress concentration factors which can be used to determine the effect of cyclic loading.

Effectiveness of Current Right-of-Way Monitoring Processes

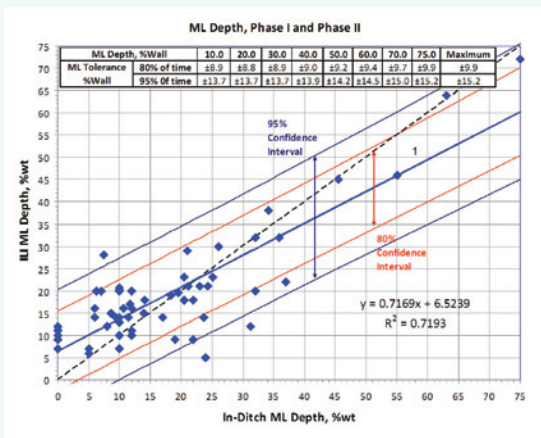
Pipeline industry statistics have consistently shown that mechanical damage by unauthorized encroachment or excavation is a leading cause of pipeline incidents that result in damage to the system and releases. The standard practices used by oil and gas transmission pipeline operators to prevent unauthorized excavations and encroachments on their rights-of-way in order to protect their buried pipelines from being damaged include relying on “one-call” networks and accurate maps, patrolling their rights-of-way, permanent markers and ROW (right-of-way) maintenance, and public awareness to help ensure that no excavation or encroachment takes place without their knowledge and supervision. This research project provided a critical evaluation of the effectiveness of the processes used by the pipeline industry to prevent damage and monitor pipeline ROW corridors. The primary method of evaluating the effectiveness of the practices and processes currently implemented by operators was through data collected and compiled in the Common Ground Alliance Damage Incident Reporting Tool (DIRT). In this project DIRT data were obtained from pipeline operators accounting for 78,000 miles of North American pipeline infrastructure. In addition, the cooperating pipeline operators were asked to submit additional data that indicated the sizes of their systems, the numbers of one-call notifications received, and the details of incidences of hits or near misses in terms that allowed root causes to be postulated.

KEY PROJECT RESULTS

The DIRT data reveal that the current one-call system works as it is supposed to more than 99% of time. Consistent with the findings of previous studies, the information gathered in this study confirms that 95% of the one-call tickets handled by pipeline operators are cleared without the need for locating and marking a pipeline facility. In contrast, the DIRT data reveal that 55% of the hit or near-miss incidents arise in conjunction with encroachments where no notification was given by the excavator. The DIRT data (i.e., the numbers of hits or near misses associated with a one-call compared to those associated with no notification) suggest that the probability of an excavation contractor, municipality, county, or other utility carrying out an excavation without making a one-call is about 44%. By comparison the data suggest that the probability of a land occupant (farmer, home-owner, tenant, etc.) attempting an excavation without making a one-call is about 94%. These probabilities, particularly the latter one, strongly suggest that enhanced public awareness is needed. Reviewing and analyzing DIRT data acquired by transmission pipeline operators separately from the entire DIRT database is worthwhile. The special attributes and circumstances of transmission pipelines such as the long distances covered, the diverse surroundings, and the stringent safety and environmental concerns, dictate the necessity for evaluating damage prevention strategies of particular relevance to these pipelines. The DIRT data can be used to measure the effectiveness of damage prevention techniques.

Investigate Fundamentals and Performance Improvements of Current In-Line Inspection Technologies for Mechanical Damage Detection

A comprehensive assessment of the performance capabilities of current in-line inspection (ILI) technologies to detect and characterize mechanical damage to operating pipeline systems was completed in two separate phases of study, with Phase 2 being completed in 2009. The project provided a comprehensive and in-depth review of the current status of ILI technologies including Magnetic (Axial MFL, Circumferential MFL), Ultrasonic (UT), and Electromagnetic Acoustic Transducers (EMATs), and Geometrical (Caliper) methods in terms of their capabilities, limitations and potentials in detection, discrimination, and characterization of various forms of mechanical damage. Assessment was completed for dents, dents with corrosion, and dents with cracks and gouges, and detailed statistical analytical methods were applied to evaluate the data in terms of their sizing and probabilities of detection, identification, and false call (POD, POI and POFC).



DML validation data from Phase I and II.

Source: Gao, M., Krishnamurthy, R. & McNealy, R., (2009). Investigate Fundamentals and Performance Improvements of Current In-Line Inspection Technologies for Mechanical Damage Detection (Phase II).

KEY PROJECT RESULTS

Validation data obtained as a result of this research documented the capability of current ILI technologies for detection and discrimination of most dents and dents with metal loss. Greater than 80% certainty of detecting and 90% certainty of identifying dents with metal loss for combined MFL and caliper technology was verified. However, the size of validation data sets may have significant impact on results and this effect will be further studied after the conclusion of this research. The results also demonstrated that current mechanical damage technologies have limited capability for detecting cracks in dents. In addition, the detection of metallurgical changes such as re-rounded dents continues to be a challenge for the current mechanical damage technologies with no capability claimed to either detect and discriminate severity. Future research focusing on reported magnetic anomaly signatures and application of in-ditch techniques capable of discriminating metallurgical changes such as strain hardening, hardness, and micro-cracks is being conducted and could benefit the understanding of capabilities for both current and developmental technologies.

The Development of Criteria/Guidelines for Welding onto In-service Chemical Pipelines

PRCI has sponsored significant research to support maintenance and in-service repair welding, including hot-tap welding. The knowledge gained in this research provided the point of departure for the application of this time and cost saving approach to the chemical pipeline industry. Research to achieve this goal was completed this year.

Safe and efficient in-service welding of chemical pipelines reduces operating costs by avoiding pipeline shutdowns for maintenance/repair welding. If safe operations can be demonstrated, these applications can be utilized throughout the chemical industry on a routine basis.

Our understanding of this technique has identified three adverse effects that may happen when welding on in-service pipelines: burn-through, hydrogen cracking, and decomposition of the product. The first two effects have been researched thoroughly in the past. The third effect, the decomposition of certain refined products, such as butadiene, propylene, and ethylene was addressed in this PRCI research project.

KEY PROJECT RESULTS

A key result included the development of criteria for in-service welding for 30 chemicals that were identified as being of interest to industry. For ease of application, the format for these criteria is similar to that used for material safety data sheets (MSDS).

It was also determined that many potential concerns can be controlled by limiting the inside surface temperature. If protection from burnthrough using the inside surface temperature approach is practiced, protection from other concerns is also accomplished. The ability to accurately control heat input levels is an important aspect of being able to weld safely onto in-service pipelines when inside surface temperatures need to be limited.

Based on a review of methods for controlling heat input levels in the field, detailed guidance for controlling heat input levels was developed.

Techniques to address other concerns that are not inside surface temperature related were also identified.

Quantification of the Effect of Dirty Upstream Pipe on Ultrasonic Meter Performance

It is not uncommon for pipelines that transport clean, dry, natural gas to also carry some level of compressor oil, glycols, black powder, and other potential contaminants. The presence of these contaminants at a metering station can affect the measurement accuracy of any of the commonly-used metering technologies, including orifice meters, turbine meters, and ultrasonic meters. Maintenance of a meter station can involve periodically taking a meter run out of service for inspection and cleaning. However, with a better understanding of the impact of meter station cleanliness on measurement accuracy and information about the meter station condition that doesn't require physical inspection, maintenance decisions can be improved.

Ultrasonic meters are known to be affected by the buildup of material inside the meter and surrounding pipe due to common pipeline contaminants. For this study, commercially-available multipath ultrasonic flow meters were installed downstream of piping that contained various levels of simulated dirt buildup with measured surface characteristics.

The project demonstrated the ability of multipath ultrasonic meters to detect changes in the condition of the upstream pipe caused by accumulated material. Identifying the severity of error in dirty meter runs allows facility operators to perform cost-benefit analyses that weigh the costs of pigging and cleaning meter runs against the potential impact of custody transfer errors and increased lost and unaccounted-for gas totals.

Assessment of Orifice Meter Flow Measurements with Low Differential Pressures

Natural gas meters sometimes operate with differential pressures (DPs) at the minimum acceptable level for proper measurement. In production applications and at production receipt points, depleted reservoirs can produce low DPs across custody transfer orifice meters, resulting in increased measurement uncertainty. A key component is the measurement uncertainty of the pressure transmitters, which are acceptable under typical flow conditions, but can interfere with accurate flow measurements in the lower DP range.

Measurement of natural gas flow with an orifice meter is a well-established practice; however, orifice measurement accuracy is impacted when flow rates are low and the DP across the orifice is at the extreme low end of common DP transmitter ranges. This research evaluated the performance of multiple types of transmitters at differential pressures simulating low flow transmission meter stations and depleted production wells. The results were analyzed to characterize and better understand the uncertainties and measurement errors associated with orifice meters operating with small bore diameters and low DPs.

KEY PROJECT RESULTS

Where low differential pressure measurements are required, it was found that measurement accuracy can be improved by the use of high accuracy or high-frequency-response transmitters. An uncertainty analysis was also performed to quantify various sources of error in low DP flow measurements.

Evaluation of Byproduct Emissions From Gas Turbine SCR Catalyst

Exterran Holdings, owner of the largest fleet of compression equipment in North America, has introduced TURBOSHIELD™, a turbocharger management system for pipeline and gathering system engines. TURBOSHIELD™ is the result of a 2006 PRCI project conducted by Kansas State University to develop the capability to monitor and trend turbocharger performance. Field tests on Panhandle Energy units in eastern Kansas provided key information about system functionality and integration. As pipeline engines are forced to comply with more restrictive air permits, their margin of permit compliance continues to narrow, and TURBOSHIELD™ provides the ability to track in real-time whether the turbocharger is maintaining its design performance and providing the excess combustion air flow necessary for low-NOx operation.



Source: Exterran Holdings

In addition, the system allows operators to identify the most economical time to overhaul a turbocharger (due to its performance degradation pattern) and monitor daily performance indicators. TURBOSHIELD™ utilizes the output of temperature, pressure, and speed sensors embedded within the turbocharger casing; these can be retrofitted into most units. The

system takes the data off the turbo and analyzes the operating data to determine engine air flow rates and air pressures, and thus turbo performance. Financial and operational reports can be generated and when the system is applied across multiple units, asset management concepts can be applied to the turbocharger fleet – thus reducing O&M expenditures, minimizing downtime, and optimizing overall performance. Research in the PRCI emissions reduction for legacy engines program has confirmed the criticality of stable turbocharger performance for maintaining aggressively lean air/fuel ratios in the combustor cylinders.

TURBOSHIELD™ is ETL-certified for Class I Div 1 or Div 2 installations. Exterran fully supports the system from onsite installation and supervision to software assistance and data analysis. This will play a very useful role in ensuring that operators can manage the narrower margins of compliance they will face in the near future.

KEY PROJECT RESULTS

This project provides the first opportunity to fully monitor and evaluate turbo performance in real-time. The gradual decay of turbocharger output over time is otherwise very difficult to track, and TURBOSHIELD will enable operators to avoid incurring meaningful performance degradation that could lead the engine to impinge on air permit compliance margins, as well as provide an asset management tool to oversee the O&M profile and pending maintenance needs of the turbochargers. Turbochargers represent a significant component investment, and a fleet approach to their management should unlock O&M cost savings, as well as allowing field staff to be proactive with unit maintenance rather than responding to out of compliance units, handling turbo wrecks or frequently adjusting a deteriorating turbo (such as with new nozzle rings) to attempt to comply with ambient or load changes.

Alternatives to Gas Turbine Expansion Starters

Current gas turbine expansion starters use pressurized pipeline gas regulated down to relatively low pressures (e.g. 150-200 psig) and expand the gas to atmospheric pressure through a small expansion turbine or helical screw and transmit the resulting horsepower to the gas turbine to accelerate it to light-off and self-sustaining speeds. Although the expansion starter is fairly inexpensive, the large quantity of gas required to start the turbine is vented to the atmosphere and results in high operating costs (particularly for large turbines with long purge cycles) and significant greenhouse gas emissions.

This project was contracted with Southwest Research Institute to identify alternative starter concepts and classify them according to their readiness and suitability for use with a pipeline gas turbine in typical applications. A multi-industry search of methods for generating auxiliary shaft horsepower at the scale of pipeline gas turbines was performed to identify and evaluate any possible concepts for starting gas turbines.

KEY PROJECT RESULTS

The search identified over 30 potential concepts that were classified as either “readily available,” “adaptable,” or “new.” Detailed cost and performance information was gathered for the readily available concepts to perform a quantitative concept comparison for various pipeline application scenarios.



Of, By and For the Energy Pipeline Industry

Of worldwide pipeline industry organizations.

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