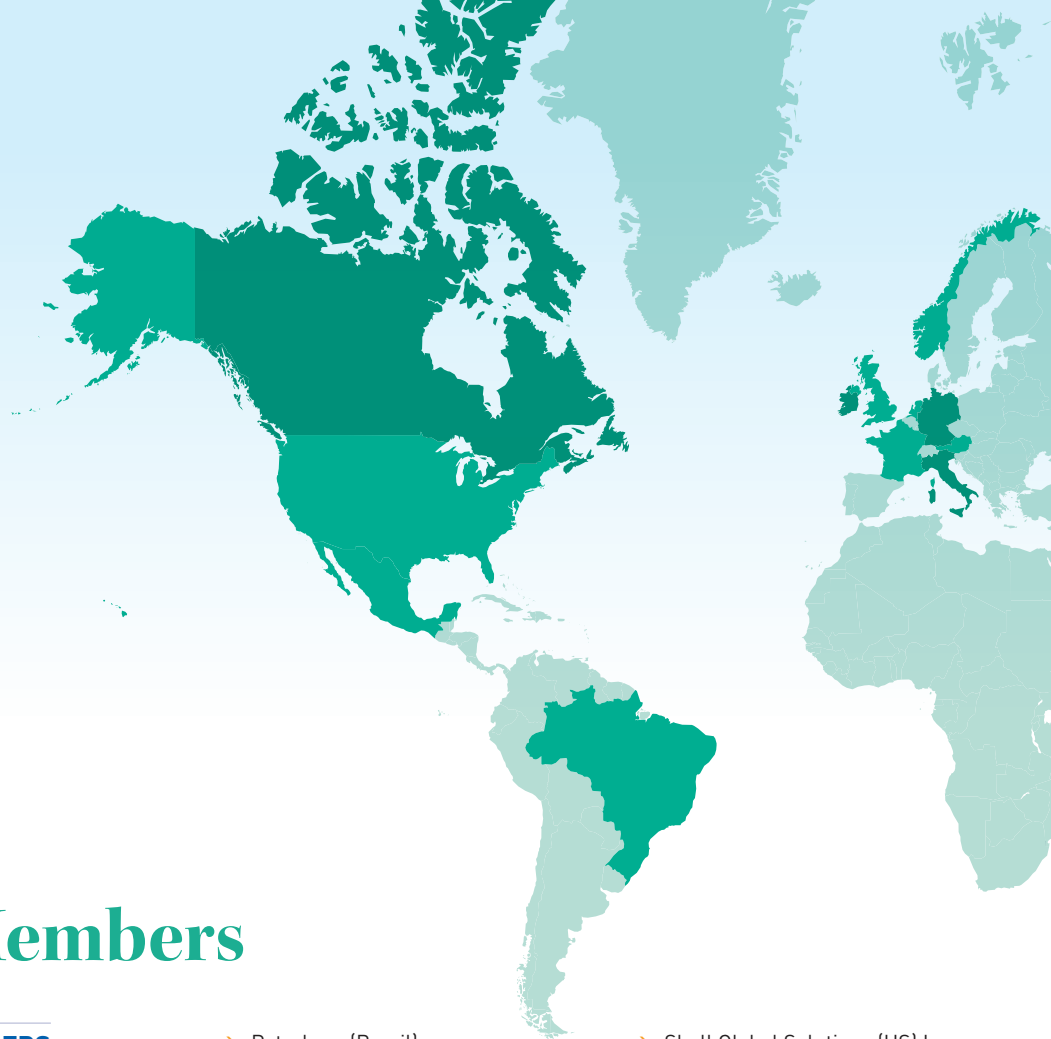


Year in Review | 2016





Our Members

PIPELINE MEMBERS

- Alliance Pipeline Limited (Canada)
- ATCO Pipelines (Canada)
- Boardwalk Pipeline
- BP
- Buckeye Partners, L.P.
- Chevron Pipe Line Company
- Colonial Pipeline Company
- Columbia Pipeline Group
- ConocoPhillips
- Dominion Transmission, Inc.
- Enbridge Pipelines Inc. (Canada) &
- Enbridge Energy Partners LP
- Energy Transfer
- ENGIE (France)
- Eni S.p.A. (Italy)
- Enterprise Products
- ExxonMobil Pipeline Company
- Gassco A.S. (Norway)
- Kinder Morgan
- Koch Pipeline Company, L.P.
- Marathon Pipe Line LLC
- N.V. Nederlandse Gasunie (Netherlands)
- National Fuel Gas Supply Corporation
- National Grid (U.K.)
- Pacific Gas and Electric Company

- Petrobras (Brazil)
- PetroChina Pipeline Company (China)
- Phillips 66 Pipeline LLC
- Plains All American Pipeline, LP
- Saudi Aramco (Saudi Arabia)
- Shell Pipeline Company LP
- Southern California Gas Company
- Spectra Energy Transmission, LLC
- Total S.A. (France)
- TransCanada PipeLines Limited (Canada)
- TransGas Limited (Canada)
- Williams Companies, Inc.

PIPELINE INDUSTRY ORGANIZATIONS

- Association of Oil Pipe Lines
- Electric Power Research Institute
- Operations Technology Development

ASSOCIATE MEMBERS

- Applus RTD
- Baoshan Iron & Steel Co., Ltd. (China)
- China Petroleum Pipeline Bureau (China)
- GE Oil & Gas
- RCP Inc.

- Shell Global Solutions (US) Inc.
- Sonomatic Limited (U.K.)

TECHNICAL PROGRAM ASSOCIATE MEMBERS

- Aegion Corporation
- Australian Pipelines & Gas Association – Research & Standards Committee (Australia)
- Baker Hughes, Pipeline Inspection
- CNPC Tubular Goods Research Institute (China)
- Dresser-Rand Corporation
- Elster-Instromet N.V. (Belgium)
- Emerson Process Management
- Enduro Pipeline Services, Inc.
- Evraz Inc. NA (Canada)
- Hoerbiger Kompressortechnik Holding GmbH (Austria)
- i2i Pipelines Ltd. (U.K.)
- Innospection Ltd (U.K.)
- JFE Steel Corporation (Japan)
- KROHNE, Inc. (Germany)
- The Lincoln Electric Company
- NDT Global (Ireland)
- Nippon Steel & Sumitomo Metal Corporation (Japan)
- Quanta Services - Inline Devices, LLC
- Riccardelli Consulting Services

-
- PIPELINE RESEARCH COUNCIL INTERNATIONAL
- Year in Review 2016
- PRCI

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

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Letter from the Chairman

— Phillip DePriest



As we start a new year, it is important for us to take a moment and reflect upon the significant achievements and improvements that were accomplished in 2016 within PRCI. In the last year, we have implemented a number of strategic changes to enable greater member engagement and to enhance the value that our members derive from PRCI.

First, following the recommendations of the Governance and Research Ad hoc Task Groups, we established the Executive Assembly (EA), replacing the Board of Directors; Executive Board (EB), replacing the Executive Committee; the Research Steering Committee (RSC), and created Research Objectives (RO). The ROs provide the over-arching guidance for developing our research portfolio and defines the majority of our research efforts. For a list of the current ROs, please visit the Research section of our website, or turn to page 5 of this Year in Review.

The RSC is essential for ensuring the success of the research portfolio. In 2016, the RSC reviewed all of the multi-year projects to confirm they were aligned with the ROs, progressing according to the plan, and tracking to their stated end points. This is the first cross Technical Committee review of the research portfolio. The RSC will be responsible for recommending any changes or enhancements to the ROs, and will assess the status of older projects to confirm their timeliness and relevance. I would like to commend the RSC for their efforts in 2016 and continuing guidance and oversight.

In the last year, we have implemented a number of strategic changes to enable greater member engagement and to enhance the value that our members derive from PRCI.

Secondly, PRCI has launched a new website and member database (PRIME). A substantial effort has been made to develop a website with the members and end-users in mind, enabling access to all of the essential information you require in an improved interface. Take a look at the new site (www.prci.org) and pass along your feedback. I'm confident you will be pleased with the enhancements and increased value for your membership and participation. I want to thank Natalie Tessel and Gary Choquette for their time and commitment in leading this endeavor, as well as the many member representatives that provided valuable input. Great work!

Finally, we are in the process of developing the 2018 – 2022 Strategic Plan. We continue to look for opportunities to improve and maximize value creation for our members. Again, many thanks for the member representatives that have contributed to this effort. This is a great opportunity to position PRCI for the future.

The tremendous successes and accomplishments of PRCI continue to be made possible by the participation and engagement of the membership community, industry researchers, and PRCI staff in helping turn vision into results. **Value creation requires participation.** I encourage each of you to actively explore how your company is engaged in the work that is occurring within PRCI and putting into practice the valuable results available from PRCI.

Phillip H. DePriest

Letter from the President

— Cliff Johnson



Wow, what a bumpy ride 2016 has been for the oil & gas pipeline industry. As the economic downturn persisted for the industry, many energy pipeline companies and their ancillary service and equipment providers have continued to look for ways to reduce costs. We have also seen a number of large mergers – notably TransCanada & Columbia Gas and

Enbridge & Spectra – that will reshape our industry for years to come.

PRCI has not been immune to the economic environment, and we know that research & development is sometimes perceived as providing returns that are only realized well into the future rather than bringing value home today. This thought process may lead companies to look to cut their level of funding for research. But our members have taken a different approach and have pushed us to provide greater value in the near term and to position them for the future. As noted in the Chairman's Letter, PRCI has just implemented a new website to enable our members to extract the value of the research more readily. The new site will develop an online community for our members and is a new key point of technology transfer.

Now is the time to
invest in Research &
Development!

At the 2017 Research Exchange, a presentation from Chevron detailed how they systematically derive value from PRCI and leverage the Technology Development Center (TDC) to the fullest to benefit their company (additional information about the TDC on page 9). This was a great example of how the information developed in PRCI can be utilized to provide direct economic impacts. Remember, as a member of PRCI you have access to over 60 years of research.

Another opportunity that has developed over the life of PRCI is that we have developed a great resource of information for training and developing young professionals in your company. With the seven Technical Committees, we have a number of key reports for all facets of operations of your critical pipeline systems. The TDC also provides the opportunity to train and test NDE professionals on any number of tools using our pipe samples.

As you read through the rest of the Year in Review, I would encourage you to ask yourself how your company can use this information to improve your pipeline infrastructure, how we can impact key industry standards, or whether the industry can identify a regulation that could be enhanced through the findings.

Now is the time to invest in Research & Development!



1

2016: A Year of Enhancement & Improvement



his year, PRCI made enhancements to its governance and research models to improve organizational efficiency and effectiveness. In an effort that has spanned nearly two years, task forces made up of PRCI members and staff worked diligently to closely analyze PRCI's current structure, operations and processes and identified opportunities for improvement.

The resulting recommendations directly addressed feedback from the members and identified process improvements and efficiencies to enable members to more readily engage with PRCI and better realize the ensuing benefits.

Part of these changes included restructuring the governing bodies to form an Executive Assembly consisting of a representative from each PRCI pipeline member company, a streamlined Executive Board to provide strategic and operational guidance for the organization, and a newly established Research Steering Committee to oversee the Research Portfolio as currently implemented by the seven existing pipeline and facilities Technical Committees: Corrosion; Design, Materials & Construction; Integrity & Inspection; Surveillance, Operations & Monitoring; Measurement; Compressor & Pump Station; and Underground Storage.

Additionally, PRCI responded to the need to prioritize and execute key research initiatives in a timely manner. The establishment of Research Objectives (RO) for the organization will assist in driving our Research Portfolio and ensuring that we are addressing the key challenges facing the oil & gas pipeline industry.

In February 2016, the Executive Assembly ratified the following ROs as guidelines for project development going forward.

- Develop and/or validate technology and analytical processes that are capable of characterizing pipeline material properties with sufficient accuracy for application in pipeline integrity assessments.
- Develop and Enhance ILI technology to reliably detect, size and characterize indications that may be harmful to the integrity of the pipeline.
- Develop, evaluate and enhance NDE technologies and operator & data analyst performance to define the condition and assess the integrity of pipeline, facilities and associated infrastructure from outside or above the pipeline or facility.
- Improve the accuracy and application of Fitness for Service methodologies by reducing uncertainties. Define, understand and improve the key factors, including models that are involved in design, construction or integrity assessments of any component in systems covered by PRCI.
- Develop, demonstrate and validate repair systems, including those that can be deployed on in-service facilities. Determine the useful life and safe operating envelopes of such repair systems.
- Develop, demonstrate and validate intrusion monitoring and surveillance technologies to

enhance detection of third-party activities, ground movement and interferences potentially affecting pipeline infrastructure.

- Reduce all releases, i.e., leaks and emissions, from all parts of hydrocarbon production, storage and transport infrastructure by developing, demonstrating and validating processes and technologies to detect, locate, measure, quantify and mitigate such releases.
- Enhance operational efficiency, flexibility, and availability including measurement functionality*, accuracy, characterization of flows and custody transfer at all points in production and delivery infrastructure including liquid pumping and gas compressor stations and all storage systems.

*Functionality includes proper operation reliability and repeatability of measurements.

These enhancements to the model have provided the structure and accountability needed to focus PRCI members on a unified and collaborative research agenda with key industry drivers that will focus on technology transfer, implementation of results, and a wide application of outcomes.



OUR MISSION

To be the global leader in collaborative energy pipeline research that provides safe, reliable, environmentally conscious and efficient means of delivery.

PRCI'S VALUE PROPOSITION

PRCI leverages our members' resources to create a research forum of ideas and results producing solutions that assure the safe, reliable, environmentally sound, and cost-effective pipeline transportation of energy to consumers worldwide.



2



PRCI Technology Development Center



The year 2016 proved to be a productive and exciting one for PRCI's Technology Development Center (TDC) in Houston, Texas. In addition to the successful completion of key industry research projects, new capabilities were added to the TDC which enhance its standing as a world-class research and development facility for the service of the pipeline industry.

This year PRCI completed the construction of a 6-inch liquid flow loop at the TDC. The design incorporates the ability for continuous test cycles, and has the physical space and access to include a variety of pipeline configurations that can be encountered in pipelines ranging from the easily piggable to "difficult to inspect." The availability of a flow loop facility will enable independent research identified by the PRCI R&D roadmap on ILI tools using liquid-coupled sensor technology. PRCI members are already utilizing this new facility by conducting quantitative performance evaluations of smart pigging and other NDE tools for liquid pipelines in difficult-to-inspect areas. This project is adding test spools that have real world and manufactured defects as well as difficult to inspect piping. Additionally, PRCI plans to extend the capability of the flow loop by adding a 12-inch pipe in 2017. Another research area addressed by the flow loop is subsea. This is of key importance for a number of PRCI members and will be a key asset in Houston for future partnerships with the widest set of subsea operators. Other future opportunities for testing using the liquid flow loop include leak detection research.

With respect to research outcomes, this year the TDC has enabled PRCI operators to establish and qualify processes for in-line inspection (ILI) technology evaluation and enhancements. By

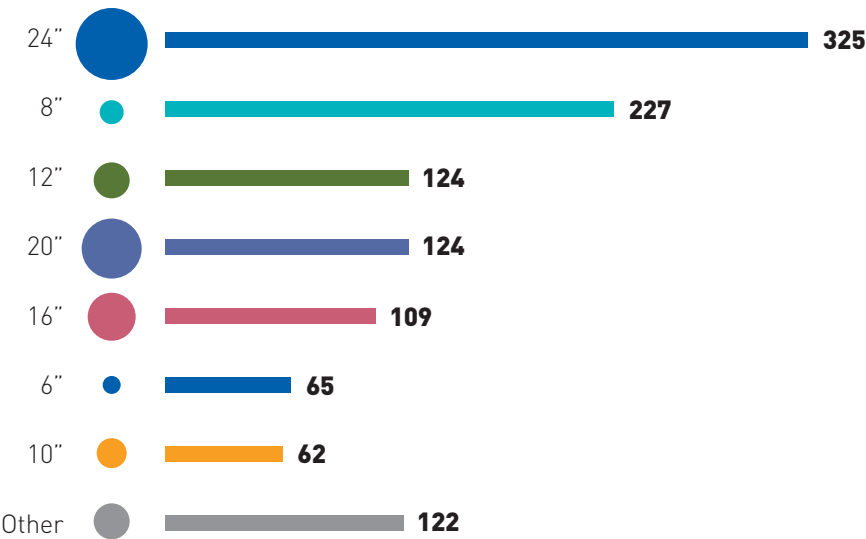


utilizing the ILI pull test rig at the TDC, PRCI-funded research has led to an increased knowledge of ILI technology performance and identification of gaps where new technology is needed. In addition, the population of pipe samples at the TDC continues to grow to over 1,100 samples with a large variety of diameters and defect types, both real and manufactured. Work on high-resolution NDE using the pipe samples available at the TDC have provided PRCI members with integrity management solutions for difficult to inspect pipelines. In 2016, \$2.4MM of funding was directed to research projects that utilized the TDC. Additionally, a number of non-ballot activities including PRCI-led consortia and third-party testing were successfully executed yielding valuable results to the participating organizations.

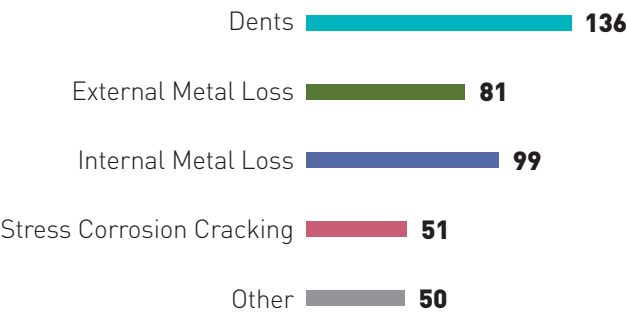
In addition to research, a number of activities at the TDC focus on technology transfer and training. PRCI members have utilized the warehouse space at the TDC to administer

Available Pipe Samples

by Diameter



by Defect Type



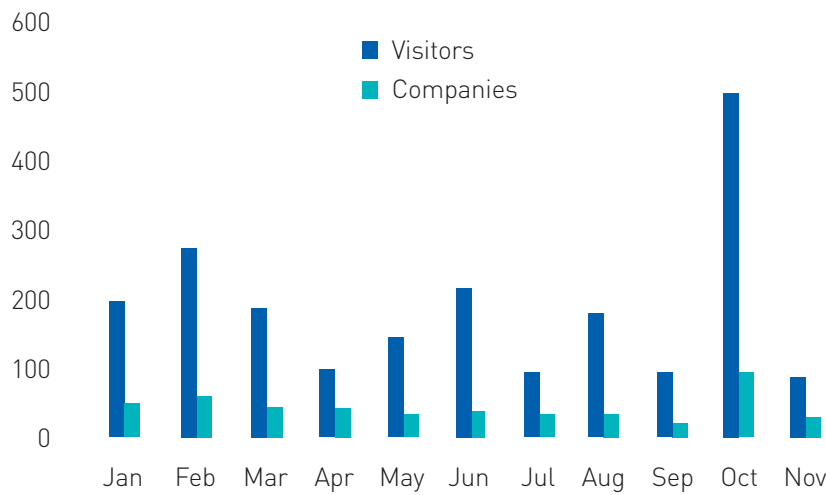


examinations of field NDE personnel, and have conducted technical training and meetings using the facility's state-of-the-art conference rooms. Hosting welding personnel qualifications and training is another opportunity at the TDC, as one aspect of training new pipeline professionals with the real world pipe samples that are unique to the TDC.

All of PRCI's Technical Committees have met at least once at the TDC in 2016, enabling meeting cost savings and providing conferencing options as a response to travel restrictions. The TDC also hosted a number of industry meetings and facility tours. These events enabled participants to gain a better understanding of the technical challenges facing the pipeline industry, and the opportunities for technology-based solutions to address integrity threats.

PRCI would like to acknowledge the members of the TDC Advisory Committee, Jeff Whitworth (Shell Pipeline), Chair; Eric Amundsen (Energy Transfer), Bill Byrd (RCP), and John O'Brien (Chevron), for their dedication and support, as well as the PRCI member companies that have and continue to contribute samples and whose direct financial support supplements the TDC's operations.

Total Visitors by Month



TECHNOLOGY
DEVELOPMENT CENTER
BY THE NUMBERS

2,100+

Visitors in 2016

1,100+

Pipe sample inventory

\$2.4MM

of research projects in 2016
using TDC

6" & 12"

liquid flow loop

3

strings in our state-of-the-
art pull test facility: 24",
16" and 12".

20,000+

square feet of indoor warehouse space

Up to 40,000 lbs

can be pulled via winch



A person wearing a hard hat and safety gear is working on a complex structure made of many thin, curved rods. The person is using a tool to manipulate the rods. The background is a solid blue color.

3



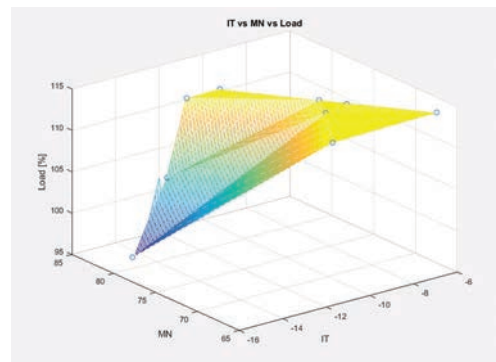
Accomplishments & Important Findings in Research



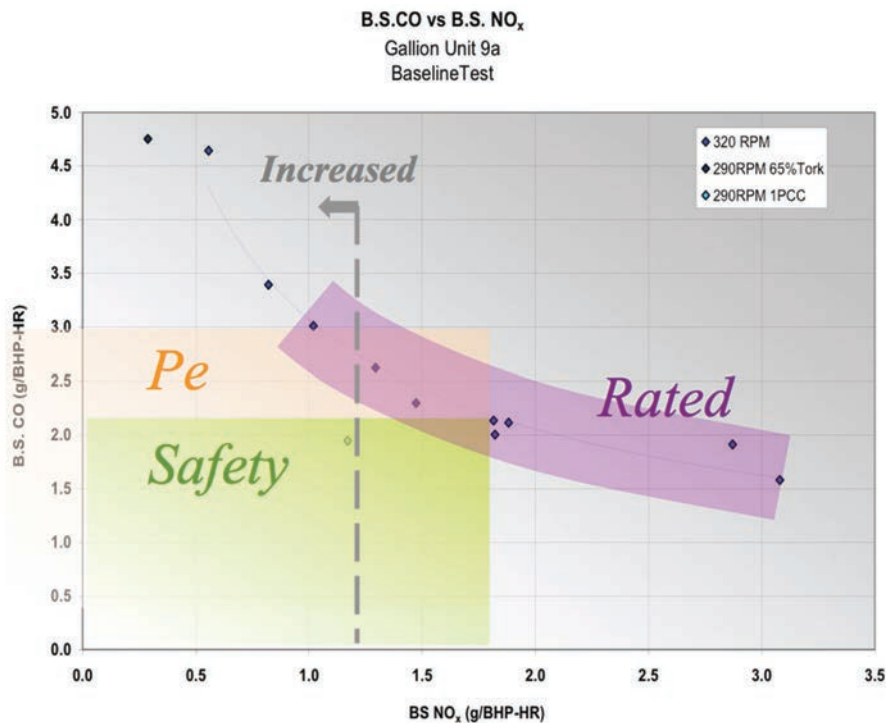
RCI members support the research portfolio with technical leadership and expertise, funding and other valued material contributions, and the time and resources required to deliver intelligence and technology that address the needs of the worldwide pipeline industry and, by extension, the global energy consumers.

Compressor & Pump Station

- Performing data mining from existing test data to examine the impact of retrofit technologies and operating parameters on greenhouse gas emissions. CO₂, CH₄, and CO₂e (equivalent CO₂) emissions are the focus of the study. The data analysis is focused on four main categories, engine performance maps, retrofit technology, uncontrolled parameters, and NO_x permit level. Examination of the impact of equipment replacement was also performed.
- Work was completed to develop chemical reaction models for non-selective catalytic reduction of emissions from rich burn engines. The work completed this year focused on evaluating the effects of dithering the air/fuel set point around the stoichiometric point. There is limited experimental data to suggest that dithering can be effective, but little is known about how dithering impacts the performance of a three-way catalyst to destroy pollutants from natural gas-powered engines.
- Work was completed to refine and validate new control methods to reduce engine emissions on a Solar Mars 100 during startup/shutdown and light load conditions.
- Research was completed to understand turbine formaldehyde emissions as compared to ambient levels and the associated challenges to measure formaldehyde concentrations less than 100 parts per billion (ppb). Extractive Fourier Transform Infrared (FTIR) methods were developed for combustion exhaust formaldehyde measurement. Measuring the ultra-low levels from turbines, commensurate with the NESHAP standard, creates significant challenges.
- Work evaluated the effects of variable fuel quality on a large bore 2 stroke natural gas engine by varying ethane in the fuel gas from 5 to 25%. Multiple air/fuel control strategies were evaluated at a nominal 2 g/bhp-hr NO_x emissions level as well as the potential for variable fuel composition to cause auto-ignition on conventional combustion engines. Ignition timing was found to be the most effective method to control engine auto-ignition. Fuel composition and TER were shown to have a significant effect on the severity of auto-ignition. It was noted that persistent auto-ignition lead to a steady increase in NO_x production, but NO_x values alone were inadequate to quantify auto-ignition. At completion of engine testing the operational parameters were analyzed to create predictive models to determine if the engine would begin to auto-ignite based on fuel composition, ignition timing and TER. The generated models accurately predicted the auto-ignition level of the engine.



- Derived from automotive technology, ion sense utilizes post ignition ionization measurements from a standard spark plug. When measured from a spark plug mounted in a PCC ion sense provides a wealth of previously unavailable information on misfire, instability, flame initiation, early flame propagation, in PCC air/fuel ratio, etc. Work was completed that investigated the use of ion sense data collected in the pre-combustion chamber to monitor and control in PCC air/fuel ratio, main chamber air/fuel ratio and the timing of combustion events in both. This paper reports on the results of this testing as well as describing the optimization strategy developed which is applicable to the full range of pipeline engines.
- Work was completed that summarizes the outcome of the Emissions Reduction for Legacy Engines (ERLE) program. The overall objective was to develop technical options that allow 80% of legacy engines to achieve anticipated NO_x requirements (approximately 0.5 g/BHP-hr), with no increase in other emissions or fuel consumption, no decrease in operating range or stability, and costs ranging from 1/6 to 1/3 of new engine replacement costs. The program culmination consisted of field tests of two typical pipeline engines retrofitted with suites of these technologies.

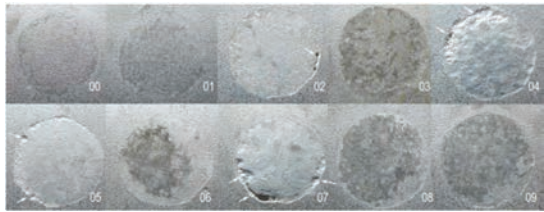
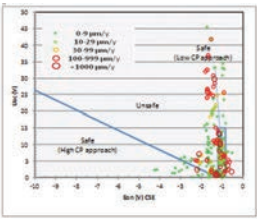
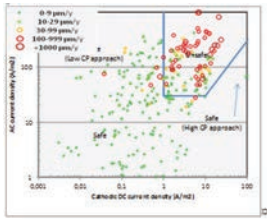


- A study was completed to demonstrate that a guide vane field refurbishment process and improved maintenance practices are effective at preventing corrosion and lock-up of the guide vanes of Solar's Taurus 60-7802S gas turbine operated in intermittent duty. A Taurus 60 engine was refurbished and operated over a five year period using maintenance practices to slow the build-up of corrosion. The visible condition of the variable guide vane assembly on this Test Unit was monitored and the guide vane actuator force measured to assess if corrosion build-up was occurring. A second co-located Taurus 60 served as a Control Unit to validate that the environment and operating profile were conducive to corrosion build-up. The Control Unit was not modified with the exception that electric actuators were installed on both units so that the actuator force could be measured. The engines logged over 18,000 hours of operation during the test period after which, both units were pulled for overhaul. A detailed inspection and

assessment was completed with extensive photographic documentation of the condition of the hardware. The actuator force measured during the start sequence for each of the engines was compared. The primary conclusion from the study is that the refurbishment and maintenance practice changes resulted in a slower rate of corrosion.

Corrosion

- Studied the impact of testing voltages used for holiday detection on the long term integrity of FBE coatings, to determine the optimum testing voltage for locating holidays on FBE-coated pipelines without causing coating damage, and also to establish an optimal grounding procedure for holiday detection.
- Studied the effect of fluctuating AC interference phenomenon on the corrosion risk of pipelines. Underground transmission pipelines that share the right-of-way corridor with electric transmission lines are susceptible to AC corrosion. Established AC criteria do not take into account the consequence of fluctuating AC voltages. The research showed that the AC-induced corrosion threat can be controlled through a two-step approach. This work provides a better understanding of how AC interference influences corrosion rates.

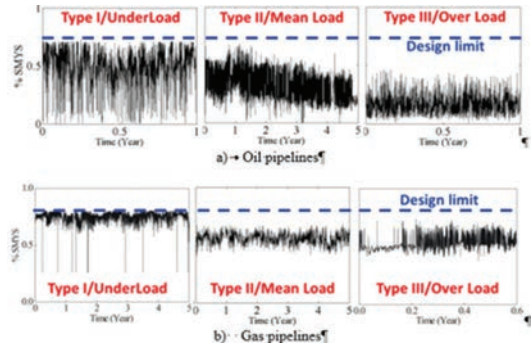
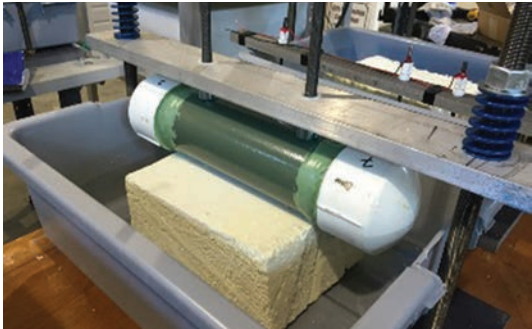


- Evaluated the effectiveness of External Corrosion Direct Assessment (ECDA) as an inspection methodology and integrity assessment process. The research evaluated the practices and procedures from a broad array of pipeline companies. The questionnaire looked for successes and failures with the ECDA process, correlation with other assessment methodologies and issues/gaps with processes and standards. Procedures were compared to industry standards and leading practices in order to help determine the overall effectiveness of the ECDA processes. The results will help operators improve the effectiveness of their ECDA programs.
- Determined the kinds of pressure fluctuations that represent the greatest risk for increasing the potential for SCC to form and propagate, the different types of mechanisms that are operative in the near neutral pH environment, and the factors that control the extent to which the mechanisms will occur. The research provides a comprehensive understanding of the effect of pressure fluctuations on the growth of NNpH SC, and will help operators design improved line pressure schemes during routine operation.
- Developed a technically defensible procedure to classify corrosion defects as active, inactive or cannot be determined. It is recognized that many factors can influence corrosion status determination and that no method will provide 100% accuracy. A field manual is provided that

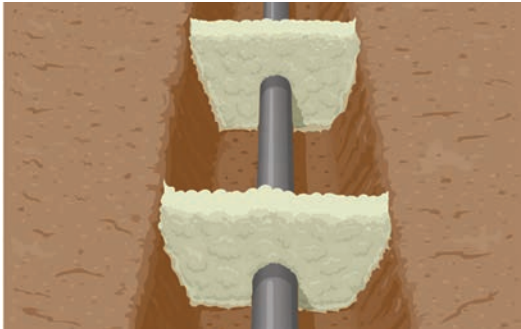


will help field technicians identify different types of corrosion scenarios. The research provides a consistent approach for the industry and will greatly benefit efforts to establish re-assessment intervals based on specific technical criteria.

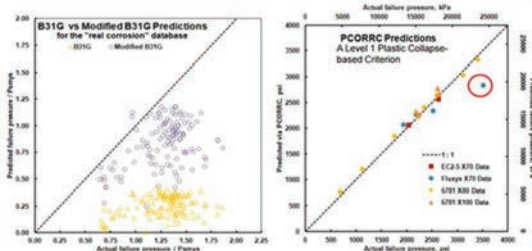
- Examined the use of structural spray polyurethane foams (SPF) used in the pipeline industry as line supports (foam ditch pads) or as erosion-control devices (foam trench breakers). Of particular concern are requirements that pipelines are protected by “non-shielding” coatings and that cathodic protection design must consider “electrical shielding.” Cathodic protection current may pass through or around the foams depending on the foam properties, surrounding electrolyte conductivity, and foam bonding to the pipeline. The program studied SPF impacts on cathodic protection of underground steel pipelines, and demonstrated that as-supplied foam materials exhibit a wide range of resistivities.



- Reviewed the long-term field performance and the failure modes and effects of fusion-bonded epoxy (FBE) external pipeline coating. Field data obtained from PRCI member companies were used to validate information obtained from the review of the technical literature. Although all potential failure modes are considered, particular attention is paid to: the effects of operating at temperatures greater than 150F (65C); the effect of cathodic protection; and, the detection of holidays and the impact of high test voltages. The fact that FBE, even when disbonded, continues to permit penetration of CP to the pipe surface ensures that even “failed” coating does not represent an integrity threat to the pipe. The overwhelming evidence from the long-term field data obtained for this study is that FBE coatings of all generations, in conjunction with a functional CP system, have and continue to protect the pipe from external corrosion and SCC.



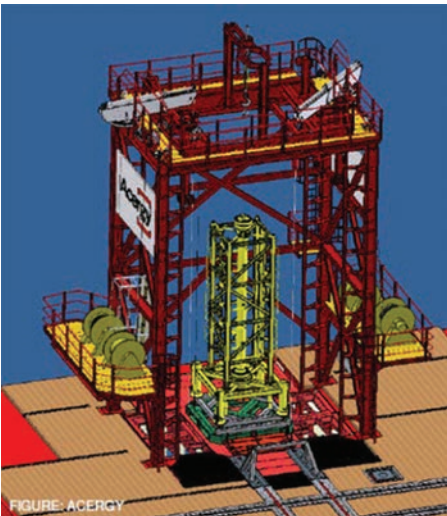
- Assessed the modeling error of current Level 1 corrosion criteria of ASME B31G and Modified B31G by quantifying the role of the shape factor (SF) and the bulging factor (BF)



as causes for the large scatter of failure predictions. Extensive elastic-plastic finite element analyses (FEA) were performed. The numerical analyses were aimed at quantifying the effect of these parameters on the SF and BF at defect failure. The FEA results were trended as the basis to reformulate a new corrosion criterion that minimizes the predictive scatter and enhances the predictive accuracy. The results will help operators optimize maintenance practices.

Design, Materials & Construction

- Guidance on Subsea Launchers and Receivers. Phases II and III were completed this year and both are available at no cost to members and for sale to others. Phase II resulted in a Guidance Document that can be used by operators to design offshore maintenance and in-service inspection programs. The document includes definitive guidance on the design of the launcher/receivers, constructability, commissioning, and ongoing pipeline operations, maintenance and inspection. Phase III performed concept-level identification and definition of potential technical solutions and/or procedures regarding specific critical subsea pig launching/receiving activities, including: lifting and handling to preclude damage to the vessel, subsea structures, reliable launch and receipt, debris handling and other potential risks. A webinar was conducted for members to review results to extract maximum immediate value from this research.



- Guidelines for Using Composite Systems to Repair High Pressure Gas and Liquid Transmission Pipelines. Composite materials are a recognized means for repairing and reinforcing high pressure gas and liquid transmission pipelines. In spite of their widespread use and general acceptance, the pipeline industry does not have a definitive standard for providing guidance in using composite repair systems. PRCI has sponsored multiple successive research programs aimed at evaluating composite repair technology for various applications encountered by operators. Most pipeline composite repair manufacturers utilize the design guidance provided in ASME PCC-2, Repair of Pressure Equipment and Piping (Article 4.1 Nonmetallic Composite Repair systems: High Risk Applications).

This project has filled that void through the development of a composite repair guideline document. The guidelines will provide prescriptive guidance based on other published work

as well as the considerable insights gained from past/ongoing PRCI studies and research performed over the past 15 years in evaluating composite repair technology. The guideline also provides essential elements for gaining regulatory acceptance of these repair methods and systems for non-temporary applications.

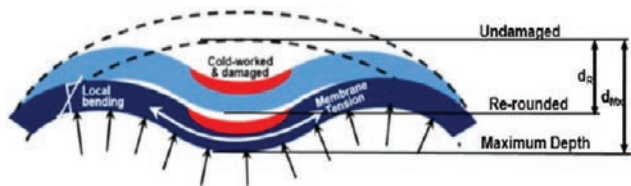
Integrity & Inspection

- Assessed the current state of the art for integrity management of difficult- to- inspect- pipelines by proposing guidance for the application of alternate inspection approaches other than hydrostatic test, in-line inspection and ECDA/ICDA currently prescribed by Code and regulations. The research examined technologies that can be applied to screen the condition of pipe wall for its full length, and direct inspection technologies with capability for obtaining high resolution wall thickness measurements at locations indicated from the application of screening technologies. The research focused on external technologies that can scan through coatings, but also reports on developing internal technologies that are not currently associated with in-line inspection.



Examples of NDE technologies for the assessment of pipe fitness for service.

- Examined the cracks in dents using pipe samples from a liquid pipeline to determine cracking mechanisms for both initiation and propagation, and assess crack growth rates and estimate dent remaining fatigue lives. This work provides guidance on repair timing and also re-inspection interval in this pipeline. In addition, a material property database was established by systematically documenting each material's chemistry, metallurgical and mechanical testing, which can be later used to support future research studies.
- Quantified the effects of re-rounding in pipelines in the wake of a damage event in relation to pressure cycling and crack growth for both vintage and modern steels. This research can facilitate the development of tools to screen for re-rounding severity in terms of metrics that are commonly quantified by ILI tools, such as local curvature or wall loss. In turn, this assists in prioritization and scheduling practical response times in cases where ILI runs identify a significant number of damage-related threats. Additionally, the outcomes of this work may



Schematic of the effects of re-rounding.

influence the design steels that are inherently more resistant to damage, without the need to increase wall thickness, with the long-term benefit of reduced susceptibility to this threat and its related cost reduction.

- Conducted experiments and analysis that will lead to guidelines to avoid delayed failures in modern steels. The experimental work developed the basis to understand and quantify the time-dependent crack growth response of three higher-strength, high toughness steels. These results confirm the expectation that such response for tough modern steels would exceed that of vintage steels, the experience with which underlies much of today's response criteria. These results in conjunction with analysis of the projected growth behavior of axial defects in pipelines led to suggested defect sizes for use in the full-scale experiments planned for future work.
- Investigated the capabilities of non-destructive examination methods to examine the quality of composite repair systems applied to pipelines. This a third phase of a multi-year effort, and the current phase of work focused on identifying suitable techniques for the inspection of the composite material, inspection of the bond quality between the composite material and the parent pipe, and inspection of the original pipe underneath the repair. The results of this study provide details of the composite repair inspection techniques trialed. The examined inspection techniques had to be capable of field deployment for pipeline and piping components. The report also contains descriptions of typical flaw types found in composite repairs (pipeline anomalies, repair debonding and delaminations), and information on techniques capable of detecting remaining wall thickness under the composite repair, e.g. using advanced ultrasonic and electromagnetic techniques.



Pipeline repair test samples containing simulated defects/anomalies.

- Completed the construction of a 6-inch liquid flow loop at the Technology Development Center in Houston, TX. The design provides the ability for continuous test cycles, and has the physical space and access to include a variety of pipeline configurations that can be encountered in pipelines ranging from the easily piggable to "difficult to inspect". The availability of a flow loop facility to PRCI members will enable independent research on ILI tools using liquid-coupled sensor technology.
- Developed a new method to determine in situ pipe properties when existing data and information are absent or incomplete. The approach uses pipe hardness, chemistry and microstructure information to determine pipe characteristics, including strength and toughness. This tool helps to fill gaps in pipeline operators' knowledge and records and provides the basis to meet the requirements of "traceable, verifiable, and complete" (TVC) records requirements and regulatory Integrity Verification Processes (IVP), where applicable.
- Developed comprehensive guidance on the use of hydrostatic testing as an integrity

management tool, within existing integrity and risk management processes, applicable to both mainline transmission pipe and facility piping. This document provides the necessary guidance to pipeline operators on the appropriate use of hydrostatic testing.

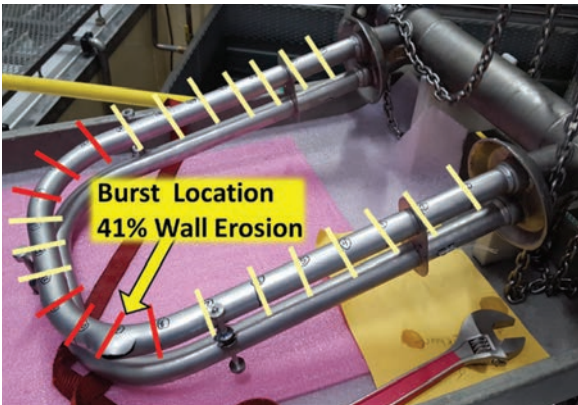
- With support from DOT-PHMSA, constructed an ILI pull test facility with 16-inch and 24-inch diameter test strings to provide opportunities for performance improvement. The major ILI technology providers, together with pipeline operators designed a series of ILI performance tests to assess the performance of MFL technologies against published performance specifications. These results affirmed the specifications were achieved. Additionally, this will provide a continuing resource for ILI technology developers, researchers and pipeline operators to have access to test samples with a range of characterized defects and pipe vintages.



- Testing showed that ILI data can confirm gross physical attributes of linepipe, such as joint length, seam type, or wall thickness. This can further support records management.

Measurement

- Multiple projects to evaluate Coriolis meter technology including assessing the ability of diagnostic routines to detect the presence of liquids (in a gas application), build-up of deposits inside the flow tubes, and erosion on the tubes. In addition, a field test was performed to assess the suitability of using Coriolis measurement for high pressure ethylene.
- An evaluation of the accuracy of equations of state to predict the measured physical properties (density, speed of sound, and specific heat) of real natural gas compositions (including shale gas) at high pressures and a wide range of temperatures. The work shows that the models are not as accurate as expected for many gas compositions. The results of this study have been shared with international standards organizations who work to improve equation of state models.
- Additional flow testing was performed to assess the impact of upstream piping and components on ultrasonic meters. Work this year focused on the impact of including gas

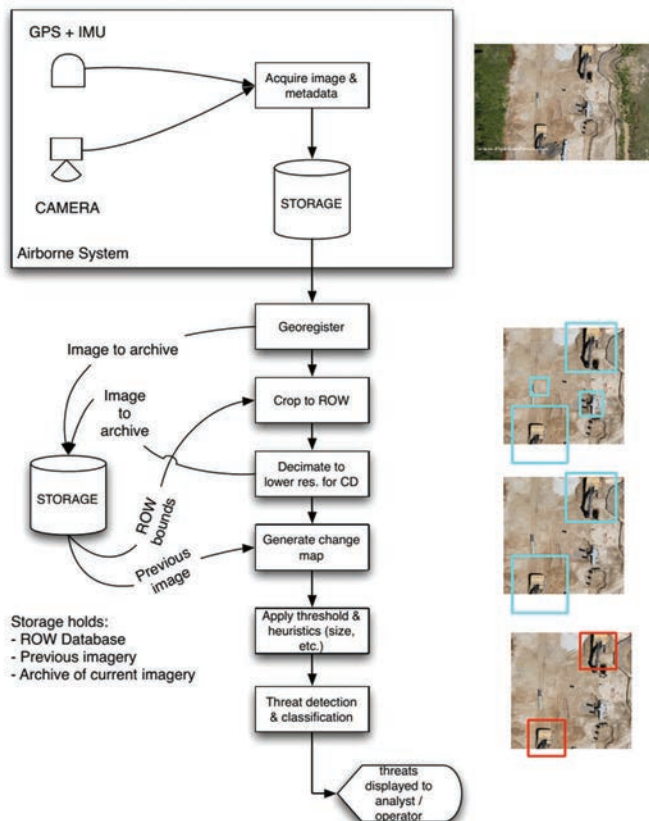


filters upstream of the meter and the impact of header configuration on meters installed in parallel.

- An evaluation of the effects of variations in orifice plate dimensions (that are all within allowable tolerances in existing standards) on flow measurement uncertainty was performed.
- The use of reciprocating gas compressors often create flow pulsations. Most measurement systems cannot accurately measure the flow rate of a pulsating gas stream, and the resulting errors can cause inaccurate gas volumes and accounting imbalances. This year, a project was completed to look for relationships between ultrasonic meter transducer sampling rates, the frequency and amplitudes of pulsations from reciprocating compressors, and meter accuracy. Diagnostics and flow data were collected from the meters and analyzed, and a useful relationship was found between the pulsation conditions and the meter measurement error. The findings were used to recommend a basis for installing ultrasonic meters in gas pipelines with varying pulsations. Additional testing evaluated a fast-response differential pressure transducer connected across a plate flow conditioner as a potential pulsation diagnostic tool.

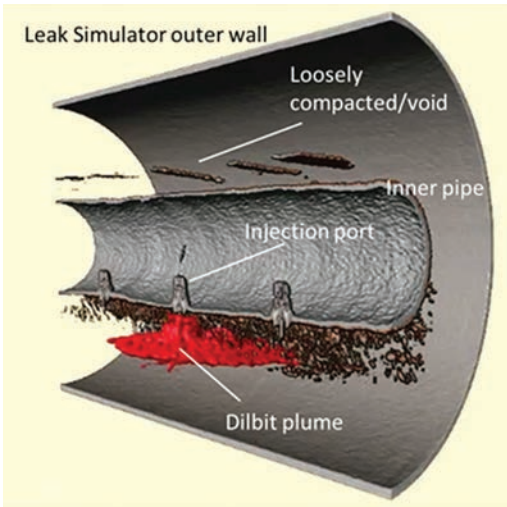
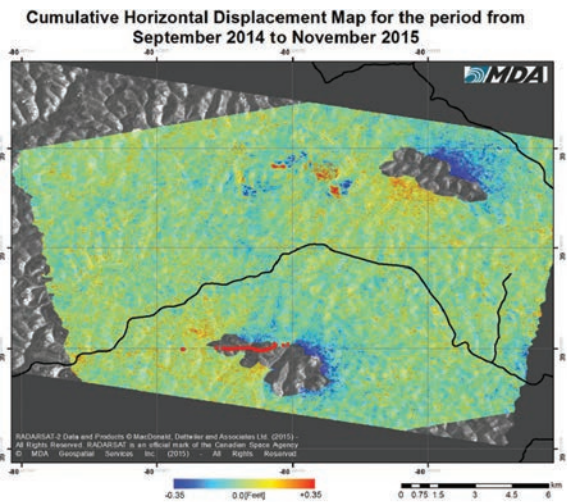
Surveillance, Operations & Monitoring

- Completed inflight validation of the Right-of-Way Automated Monitoring (RAM) Program's prototype Automated Threat Detection System (ATDS) for fixed wing airborne surveillance of a pipeline right-of-way (ROW). The hardware and software system was deployed along an approximately 150 mile pipeline corridor with results successfully meeting the Concept of Operations document originally established in the inception of the RAM program. The



prototype ATDS technology was developed in partnership with PRCI member companies, American Aerospace Inc. and University of Dayton Vision Lab. Final results are published and will be reported at the 2017 PRCI Research Exchange. The automatic threat detection software will be available in early 2017.

- Completed a satellite project to evaluate the effectiveness and limitations of using satellite- based interferometric synthetic aperture radar (InSAR) methods to measure the ground subsidence due to longwall coal mining, which is typically rapid and aggressive, and a threat to pipelines traversing these mines. The project provides an overview of the longwall mining process, and conventional methods of monitoring ground movement using InSAR and other means.
- Completed leak detection research to better understand subsurface fluid leakage and migration behavior of several hydrocarbon and soil type combinations. The project used a combination of laboratory leakage tests and numerical simulations. Numerical modelling of product leakage and subsurface migration focused upon product dispersion behavior within the trench and, to a lesser extent, gas phase migration and fate, thermal signatures and geomechanical effects upon the soil in the vicinity of the pipeline. Improved understanding of the flow and dispersion properties of liquid leaks will support the design and implementation of subsurface leak detection technologies.



Visualized leak simulator using selected CT scan data.



A person wearing a hard hat and safety gear is working in a field of tall grass. The image is overlaid with a green tint. The person is holding a tool, possibly a shovel or a probe, and is looking down at the ground. The background shows a wooden fence and some buildings.

4



Completed Research Reports

Compressor & Pump Station

- Continuous Engine Performance Monitoring Technical Specification
- Cylinder Level Sensing and Control on Typical Pipeline Engines
- Development of Field Pump Performance testing Procedure
- Field Evaluation of Oxidation Catalyst Degradation on a 2-Stroke Lean-Burn NG Engine
- Field Evaluation of Timed Power Cylinder Lube Oil Injection
- Field Test of Integrated ERLE Technology
- FTIR Formaldehyde Measurement at Turbine NESHAP and Ambient Levels
- Liquid Leak Detection Technology Review for Aboveground Facilities
- Methane Reduction Data Analysis for 2-Stroke Lean Burn Natural Gas Engines
- Modeling of NSCR Performance with Natural Gas Exhaust
- NO₂-NO_x Ratio Data Compilation and Assessment
- Prevent Variable Guide Vane Lock-up on Solar Gas Turbines Subject to Intermittent Operation
- SCR Application to Typical Two-Stroke Cycle Pipeline Engines
- SoLoNO_x Low Load Controls to Reduce Emissions for Less Restrictive Load Following
- Summary of NO₂ - NO_x Ratio Test Data for Reciprocating Engines and Combustion Turbines
- USEPA AERMOD Plume Rise and Volume Formulations and Implications for Existing RICE
- Variable Fuel Composition Air Fuel Ratio Control of Lean Burn Engines

Corrosion

- Effect of Pressure Fluctuations on Growth Rate of Near-Neutral pH SCC
- Field Techniques for Determining Corrosion Status
- Improving the Performance of the External Corrosion Direct Assessment (ECDA) Methodology
- Minimize Model Uncertainty in Current Corrosion Assessment Criteria
- State-of-the-Art Review of FBE Failure Modes and Effects
- The Effects of Spray Polyurethane Foam on the Cathodic Protection of Pipelines
- The Effects of Test Voltage on FBE Coatings
- The Impact of Fluctuations in AC Interference on the Corrosion Risk for Buried Pipelines

Design, Materials & Construction

- Assessment of Effect of Pipeline Wall Loss (Corrosion) on Strain Capacity
- Essential Welding Variables for X80 Linepipe

- Guidance Document on Subsea Launchers and Receivers
- Guidance on Subsea Launchers and Receivers
- Guidelines and Standard for Alternative to the Pre-Service Hydrostatic Testing
- Guidelines for Use of Composite Systems to Repair High Pressure Gas & Liquid Pipelines
- Sleeve End Fillet Weld Stress Intensity Factor Solutions
- State-of-the-Art: “Alternatives to Steel Pipelines”
- Strain Based Design and Assessment - Integrity Management
- Tools for Effective Welding Process and Procedure Development
- Weld Hydrogen Cracking Susceptibility Characterization

Integrity & Inspection

- Analysis of Pipeline Inspection Technologies Using Guided Waves and Ranges of Applicability
- Comprehensive Threat Assessment and Failure Susceptibility of ERW Pipe Seams
- Consolidated Report on NTSB Report PAR 09-01 and Gap Analysis
- Determining Pipe Discrepancy/Properties Using ILI Technology
- Evaluation of Time-Dependent Failure in Pipelines
- Guidelines for Use of Hydrostatic Testing
- In the Ditch Non-Destructive Mechanical Property Measurement for Vintage Low Toughness Pipe
- In-line Inspection and Assessment for Pipeline Girth Weld Defects
- Inspection of Composite Repairs for Pipelines and Piping – Phase 3 Further NDE Trials
- NDE-4F ILI Trials and Performance Evaluation

Measurement

- Effect of Upstream Piping Configurations on Ultrasonic Meter Bias
- Effect of Upstream Piping Configurations on Ultrasonic Meter Bias - Unblinded
- Variation in Orifice Plate Flow Performance as a Function of Geometric Plate Tolerances
- USM Uncertainty Estimate from Diagnostics
- Equations of State Comparison for Pipeline Compressor Applications
- In-Situ Proving Techniques for Gas Ultrasonic Meters
- Effect of Upstream Piping Components on Ultrasonic Flow Meter Accuracy - Unblinded
- Effect of Upstream Piping Components on Ultrasonic Flow Meter Accuracy
- Ethylene Measurements Using Coriolis Technology
- Pulsation Effects on Ultrasonic Meters, Phase II

- Turbine and Coriolis Meter Diagnostics with Entrained Liquids-Unblinded
- Machine Learning Algorithms for Smart Meter Diagnostics – Part II
- Review of Ultrasonic Flow Meter Installation Effects
- Testing In-Situ Coriolis Meter Verification Technology Detecting Corrosion and Erosion
- Turbine and Coriolis Meter Diagnostics with Entrained Liquids
- Ultrasonic Meter Recalibration Frequency Phase 2

Surveillance, Operations & Monitoring

- Ground-based Radar Monitoring of Pipeline Infrastructure
- Modelling and Laboratory Simulation of Subsurface Fluid Migration from Small Pipeline Leaks
- PRCI Airborne Threat Detection System Prototype Development and Analysis



5



Current Research



very year, PRCI produces a collaborative research portfolio aligning with the industry's priorities to which members allocate resources directly to projects and programs of importance to their operations and business drivers.

Compressor & Pump Station

- Reducing part load emissions on a Solar Taurus gas turbine.
- An evaluation of the effectiveness of oxidation catalyst washing.
- An analysis of the effectiveness of NSCR control system.
- Further development of emission factors for greenhouse gas emissions reporting is underway. The work includes data gathered through public (EPA) sources as well as member supplied data with a focus on the largest sources.
- There is a gap between what API recommends and how vertical pumps are actually selected and designed. There is very little guidance available on the operation and maintenance practices, coupled with this the instrumentation on these pumps is very minimum making any diagnostics or condition monitoring a big challenge. Research is underway to develop guidelines for the selection, design, operation, troubleshooting and maintenance of these vertical pumps.
- Additional field tests of continuous equipment performance monitoring for increased equipment reliability and advance notification of performance degradation.
- There are ongoing and follow-on studies to assess varying gas compositions on engine (both reciprocating and gas turbine) performance and emissions.
- Field testing of field pump performance testing procedures.
- Gathering extensive data sets to support a modification of EPA-mandated NO₂ modeling.



Corrosion

Ongoing pipeline corrosion research focuses on the technical and operational challenges related to external corrosion assessment and mitigation. The current collection of research projects aims to provide operators with practical results that can be applied directly on-site and therefore have an immediate impact on managing the corrosion threat. These initiatives include:

- Validating newly established AC-induced corrosion criteria using real-world measurements of pipeline survey data along with pipeline characteristics. These criteria were developed under a previous PRCI effort aimed at refining the existing AC Corrosion criteria and guidelines for better control and mitigation of AC corrosion.
- Assessing the effectiveness of vapor corrosion inhibitors (VCIs) for corrosion control in casing annuli and aboveground storage tank foundations. This study will provide operators with a solid foundation on when to deploy VCIs as a corrosion control strategy, and how to gauge/monitor its effectiveness over the life-cycle of the assets involved.
- Developing an improved methodology for identifying coating faults and their severity through electrolyte resistivity measurements. This project is a continuation of last year's study on enhancing the classification of coating anomalies by measuring soil resistivity as close as possible to the pipeline-to-electrolyte boundary.
- Assess high voltage direct current (HVDC) interference risks on buried pipelines by understanding the influence of HVDC system configuration and operational conditions, as well as pipeline and soil properties. This study will provide operators with a comprehensive field test protocol for on-site threat assessment, and a guidance document for predicting, assessing, and implementing countermeasures for mitigating HVDC interference.
- Evaluate AC corrosion coupons for monitoring applications. This project will identify and confirm the most significant factors impacting the sensitivity and reliability of various AC corrosion coupon assemblies. The resulting document will guide operators in selecting suitable monitoring hardware for accurate measurement and acquisition of AC corrosion-related pipeline data, and specify proper coupon installation and monitoring procedures for pipelines susceptible to AC corrosion.
- Establish the potential severity of various cathodic protection (CP) shielding parameters. The aim of this work is to develop a list of pipeline operational variables and categorize their implications on CP shielding based on literature and incident reports. This effort will work in collaboration with NACE TG 523 "Consequences of Coating Failures as Related to Interaction with Cathodic Protection."
- Determine the internal corrosion conditions that exist under pipeline deposits and the effectiveness of corrosion inhibitors in controlling under-deposit corrosion.
- Assess the feasibility of a polarization shift-based cathodic protection (CP) criteria for mitigating stress-corrosion cracking. The goal of this study is to develop a technical basis for



the use of a polarization shift-based CP criteria for mitigating high-pH SCC, in addition to the -850 mV polarization potential criterion presently used by operators.

- Improve the technical effectiveness of the stress-corrosion cracking direct assessment (SCC-DA) process as applied to near-neutral pH SCC. This study will investigate the on-site measurement of key parameters that are well connected to the crack growth mechanism to determine the NNpHSCC risk level.
- Assess the sizing of crack anomalies using in-line inspection (ILI) data to develop appropriate responses to crack ILI results. This study will feed into a database for continuous improvement and application of lessons-learned through data.

Design, Materials & Construction

- The Assessment & Repair Focus Area is of particular interest to PRCI member companies. Research continues on the long term performance of composite material repair systems for on-shore energy pipeline applications. This program is in its 8th year of a 10 year test to examine repairs on pipe joints under very realistic but simulated in-service conditions.

Improved structural integrity assessment capabilities remain a key priority. Several projects are underway to improve operator assessment capabilities, including better methodologies for integrity management of vintage girth welds, SCC crack clusters, and for defect assessment of sleeve end fillet welds.

- The Subsea research program includes the following continuing work:
 - Updates to the PRCI On-bottom Pipeline Stability Program to account for additional subsea conditions being encountered by operators, improved solution approaches and a better user interface. The major update of this program has been completed and is undergoing a thorough internal validation review prior to issuance in the coming year. Additional improvements may be included in future years.
 - Weld overlay pipes are being evaluated for subsea application with particular emphasis on in-mill NDE inspection of the weld overlay layer and fatigue performance. This serves to assure the consistent quality needed for such critical applications as subsea flowlines or tower risers. This research will be completed in the coming year.
- In the Geohazard Management Focus Area, several important projects continue, which will provide operators further guidance for predicting pipeline strains induced by slope movement, for conducting fitness for service determinations of strain- based designed pipelines that have experienced metal loss, and for the improved integrity management of pipelines that have been subjected to ground movement.
- In the Welding Focus Area, research continues to achieve greater reliability and consistency in the mechanical performance of X80 and lower grades of pipeline welds. Essential welding variables for pulsed gas metal arc welding have been established that optimize consistency in mechanical performance while providing fabricators the ability to produce welds of desired quality. For ready practical application of this methodology, a new software tool was developed that can eliminate one or more costly and time consuming weld qualification steps. This tool is currently under final user review by the PRCI project team.

- Research continues on improved guidance to avoid hydrogen cracking in the heat affected zones and weld metals. The Phase I report of this work has been completed and is available now to provide PRCI members with information to characterize hydrogen cracking susceptibility of weldments. The final phase of this research will occur in the coming year.
- In the Materials Focus Area, a materials selection tool is being developed to enable operators to efficiently consider alternatives to steel pipe. Non-metallic alternatives can be used to avoid corrosion issues or allow cost reductions where the materials handling specification either doesn't require metal, or requires expensive alloy steel. The work to develop the underlying content that will be accessed by the database has been completed and the tool will be completed next year.

Integrity & Inspection

- An alternate response criterion for plain dents or dents with stress concentrations will be finalized. By utilizing the more detailed information now available from ILI tools, this research will combine the new PRCI dent fatigue criterion for plain dents, together with other available information on ILI and dent assessment, into a proposed alternate response criterion for plain dents. After finalizing improved fatigue assessment tools for plain dents, subsequent steps will address dents on welds and dents with metal loss.
- Management of shallow dents and shallow dents interacting with shallow corrosion features is a challenging issue. With the improvement in ILI technologies, there is an increase in detection of shallow dents and shallow dents interacting with corrosion features and a large population of these features exists currently, without creating an imminent hazard, in operating pipelines. Previous full scale dent fatigue testing and dent modeling did not consider shallow restrained dents. Therefore, this study will develop a full-scale dented pipeline segment trial data set. Once completed, the project data would be usable as the basis for developing, calibrating and validating analytic and numerical integrity assessment models. The research will allow pipeline operators to enhance and implement a dent integrity management strategy based on the relative ranking and severity of the shallow restrained dents with or without interaction with secondary features.
- A variety of general NDE and ERW-specific projects will defining the current performance of a range of ILI systems for detecting, sizing, and discriminating coincident features associated with geometric anomalies, including cracks, metal loss corrosion, and dents with gouges. These data are integral to an effective ILI program to address mechanical damage to pipelines, and testing will be performed at PRCI's Technology Development Center. The testing performed and data collected will also provide a basis for developing a standard set of ILI Performance Specifications for mechanical damage. The results will be fed directly to other work in Mechanical Damage program that are addressing improved Mechanical Damage models.



Mechanical Damage samples to be used for ILI performance Testing.

- Work will continue to evaluate and quantify the performance of Large Standoff Magnetometry techniques that hold the promise of providing integrity assessments on both difficult to inspect and conventional buried pipelines. This research will examine results from field trials of available technologies to determine the reliability, correct calls, misses and false calls of these tools. While these techniques are in early stages of development, the potential to operators is substantial if they can be proven to be accurate with a high probability of detection. Establishing the application of this technology for screening pipelines prior to excavation could lead to significant savings for dig programs.
- An assessment is underway of the impact of personnel variability on NDE performance. This research will identify approaches and methodologies currently used to train NDE technicians in the pipeline industry, and potentially improve current practices, utilizing research-based best practices/strategies in teaching and learning from academia. This will be compared to parallel, basic hands-on performance demonstration of NDE testing on samples with known damage. A guidance document will be provided outlining possible ways to implement these strategies in appropriate NDE technician training.



Non-destructive evaluation technique requiring human interaction.

- Conduct a quantitative performance evaluation of available flexible pipe inspection tools and develop a guideline for how the inspection results from such tools can be used to improve the integrity assessment of flexible pipes in operation. The tool performance will be determined by performing blind tests on flexible pipe test samples pre conditioned with flaws in a lab environment. The guideline will be based on the capability of the tools to detect critical flaws combined with available flexible pipe analysis tools and industry practice for integrity assessment.
- A series of pull-through tests at the TDC will characterize MFL tool responses to metal objects of various sizes, distance from the pipe and magnetic properties. This project is expected to give operators the capability to become aware of near crossing pipelines that could degrade as a result of interference with CP systems or induced or stray currents from the other pipe.
- Other pull tests will evaluate whether low field MFL ILI technology (or other ILI deployable

technologies) can detect unsupported or stressed branch connections to that may be an integrity threat. Pull tests in the carrier pipe were conducted while varying loads were applied to the branch segment.

- Testing will further assess the capabilities of a portable frictional sliding HSD tester to generate uniaxial stress-strain curves and determine pipeline grade in the field without removing the sample. Until now, this information can only be obtained through tensile tests, which require the extraction of a material sample for testing in a laboratory, or a series of ball indentation tests to obtain a single data point using empirical techniques.
- Data gathering and analysis will expand on the successful efforts to establish an industry-wide database for the performance of modern crack detection ILI technologies. Significant results of this analysis characterized crack shape and its influence on detection, burst pressure, and differences between ILI indications and field measurements. Phase II is underway and is expanding the data gathering and emphasizing technology transfer so operators can better utilize the results on their own systems.
- Pull tests at the TDC will seek to confirm that the periodic use of the current ERW seam integrity ILI methods (UTCD, TFI, CMFL) are the best means to identify and respond to anomalies and prevent ERW seam failures. The enables a consistent and objective basis for determining the performance capabilities of the current inspection technologies, particularly as the performance relates to critical flaw sizes and sensitivity analysis of engineering models. The work will be conducted on real world samples with ERW long seam cracks.
- Developing an industry resource to improve confidence and reduce conservatism inherent in ERW fatigue damage accumulation assessments and thus improve accuracy of defect assessments and correctly define required inspection or pressure test intervals. This project is a final validation study using former in-service pipeline materials for the testing program in is the final phase of two previous projects conducted by PRCI.
- In-ditch NDE technology performance and practice continues as a program focus, via characterizing the performance of current in-ditch NDE for screening analysis and detailed anomaly sizing. The work also investigates advanced/emerging NDE technologies (e.g., waveform inversion (IWEX) ultrasonics and low frequency MWM-array) and supports the development of new technologies by identifying the limitations of the current sensor arrays for characterizing anomalies in pipe long seams. Guidelines and protocols for NDE inspection of ERW pipe long seams and qualification of tools will be developed.
- Evaluate a prototype Electromagnetic Impedance Testing (EMIT) tool that uses impedance analysis of coils producing a time-varying magnetic field. It promises to quantitatively or semi-quantitatively determine the extent and nature of corrosion and subsequent wall loss on the inner surface of unpiggable pipelines. The system will be deployed from an in-line vehicle, initially from a tethered tool and then a free-swimming pig.
- Summarizing the applicability of MFL, USCCD and EMAT for ILI inspection of pipeline girth welds. Pull-through tests and infield site excavations of operational pipelines have been conducted as the basis for defect type determination and size quantification. A comparison of test results of MFL & USCCD and EMAT technology for girth weld defects are presently in review.
- PRCI has constructed a 6-inch liquid test loop at the TDC in Houston. This project added test spools that have real world and manufactured defects as well as difficult to inspect pipping, enabling quantitative performance evaluation of various inspection devices for liquid pipelines in difficult-to-inspect areas.



- An important option for operators to comply with the new PHMSA Integrity Verification Process is the ability to conduct an Engineering Critical Assessment (ECA). PRCI will deliver a guidance document for determining the applicability of ECA to a given segment for the purpose of establishing MAOP. It will define the boundary conditions, the relevancy of the threats, and determination of the risks while being flexible and customizable. PRCI has made significant progress in the development of the various process elements that could constitute an ECA, which provides a potential alternative to hydrostatic testing.

Measurement

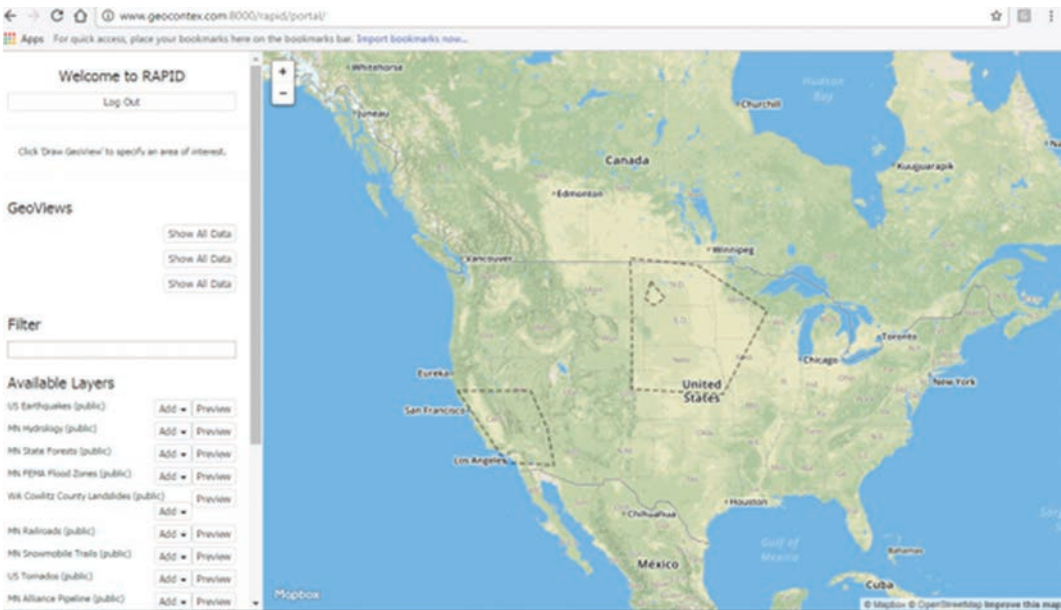
- A study to assess the minimum necessary insertion length for gas sample probes.
- An assessment of the capabilities of several static mixers to extract a representative liquid sample.
- Assessment of the impact of composite sample mixing methodology and centrifugal forces on the determination of density, sediment, and water.
- Using ultrasonic meter diagnostic parameters to estimate the measurement uncertainty.
- Assessing the performance of online instruments used to determine liquid density.
- Correlative estimation of hydrocarbon dewpoint temperatures.
- Assessing the effect of different calibration gas standards on gas chromatography accuracy.

Surveillance, Operations & Monitoring

- Unmanned Air System (UAS) platform research was continued in 2016. This advances efforts to develop UAS technology for industry applications for safer and more accurate methane leak detection from aerial platforms. Flights were conducted in partnership with NASA's Jet Propulsion Laboratory (JPL) to validate their methane detection system on both vertical-take-off-and-landing (VTOL) and fixed-wing small UAS platforms. Work will continue in 2017 to add ethane detection to differentiate between biogenic (natural) and produced methane emissions.

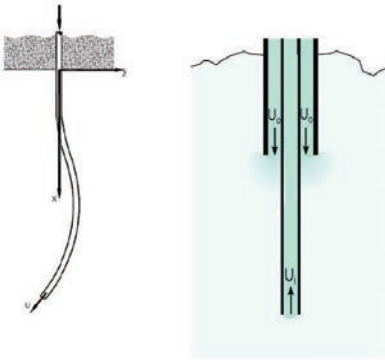


- Satellite work in 2016 was continued with the joint project the Department of Transportation (DOT) Office of the Assistant Secretary for Research and Technology (OASRT), formerly DOT Research in Innovation and Technology Association (RITA), and California Polytechnic State University. This effort focused on the use of satellites for encroachment and threat detection monitoring along pipeline rights-of-way. The project includes use of satellite remote sensing, geospatial data information, and readily available web-based datasets to enhance existing pipeline operator Decision Support Systems (DSS) for improved pipeline integrity management. The final reports and release of the web based CalPoly DSS will be released in the first quarter in 2017.



Underground Storage

- Assessment of a variety of inspection technologies that have found application in various aspects of pipeline integrity management, but which have not yet been widely used downhole. Comparative tests will provide operators with an enhanced understanding of the pros and cons of an array of in-line inspection options.
- PRCI and the Solution Mining Research Institute are cofunding an ongoing study to extend the understanding of the dynamics and flow-induced instabilities of brine and production strings used in salt-cavern applications. From operator experience, it is known that string movement/deformation and vibration is dependent on fluid velocity and various geometric parameters of the string and casing. Bench scale testing and analytical modeling conducted at McGill University is providing a quantitative framework for characterizing these factors. This theoretical investigation will also support any subsequent full scale field testing that may occur in future years. The findings from this work and future field testing will provide operators with added confidence in increasing the maximum allowable product flow velocity while maintaining brine string integrity, thus enhancing productivity.



A person wearing a hard hat and safety gear is working with a large bundle of rebar in a construction setting. The image is overlaid with a teal color filter.

6

Initiatives for the 2017 Research Portfolio



Through the collaborative research model that PRCI employs, we have developed a research portfolio for 2017 that will continue to deliver on the organization's core mission of technology development in support of safer and more environmentally friendly approaches to operating and maintaining the energy pipeline infrastructure around the world. Member funding contributions of over \$10 million and numerous in-kind support commitments were allocated to research projects addressing leak detection, pipeline operations & integrity, corrosion prevention & control, design, materials, construction, underground storage, and pipeline facilities.

Compressor & Pump Station

The largest effort of the committee is completing the data gathering necessary to improve the accuracy of EPA's AERMOD NO₂ emissions modeling program to more accurately model NO₂ ground level concentrations. This is large undertaking that involves several other industry organizations. The initial field data gathering will be completed by the end 2016. After the data gathering has been completed, extensive modeling and analysis will be performed.

New projects for the Compressor and Pump Station Technical Committee are:

- A project to estimate the exhaust residual gas fraction based on measured in-cylinder pressure
- Enhancing the reliability of centrifugal compressor dry gas seals
- Additional analysis of operator-reported greenhouse emissions data
- Follow-on work to utilize portable emissions analyzers for emissions verification
- Additional assessment of station piping layout on liquid pump efficiency and performance and associated field pump performance testing
- Evaluating alternatives to improved reciprocating engine starting reliability and reduce the engine wear associated with startup combustion instabilities
- A field trial of an electric seal boost system for centrifugal compressors equipped with dry gas seals
- Field evaluation of catalyst washing to extend the usable life of a catalyst

Corrosion

In 2017, The Corrosion Technical Committee continues its focus on industry challenges related to external corrosion prevention and mitigation, stress-corrosion susceptibility evaluation and repair, and the impacts of stray current on pipelines. These initiatives are driven by a set of roadmaps developed by the technical committee which ensure seamless integration of research results to other initiatives in PRCI and the broader pipeline industry.

- Develop guidance on the spacing needed between pipelines and AC grounding systems. If guidelines indicate that pipe/power line installation are inside the critical separation distance, then a grounding study can be initiated. The guidelines will provide general safe separation distances between AC grounded systems and pipelines.
- Research and quantify the best practices used in industry for precise location, measurement and

evaluation of DC stray currents affecting transmission pipelines. The guidelines will provide a consistent and effective approach for identification and precise location of static or dynamic DC stray current effects.

- Develop guidelines for determining the most appropriate CP coupon configuration to support integrity decisions. The coupons currently used in the industry vary widely and there are no accepted guidelines for determining the most appropriate coupon configuration, yet coupons are relied upon to support integrity decisions. Standards provide only limited information on the significance of the design parameters. The guidelines will help answer many of the numerous and lingering questions operators have about the use of CP coupons.
- Develop a tool for the failure pressure prediction of crack-within-corrosion anomalies. The tool will help operators assess the fitness-for-service of these anomalies.

Design, Materials & Construction

In 2017, the Design Materials & Construction Technical Committee continues ongoing research focused on technical issues identified in its research roadmaps in each of its seven key Focus Areas: Assessment & Repair, Design, Construction, Fracture, Materials, Geohazard Management and Welding. In addition to the continuing research, following are new initiatives for 2017.

- Assessment and Repair. While work continues on the long-term performance of commercially available composite repair systems, a new initiative will extend the recent work that evaluated available NDE for the inspection of composite repairs by assessing the significance of anomalies on the quality of the repair. Although properly installed repairs have generally performed well in service and in the PRCI long term test program, the results of this new research project will further improve management of composite repairs.
- Materials. A new project will examine the material properties of flanges and fittings. These components been observed to have a wider variability in material quality than line pipe and hence could pose a vulnerability to overall system integrity management.
- Design & Construction. For onshore pipelines a project has been started to improve the analysis of exposed river crossings. As streams and rivers meander, creating new hydraulic forces and erosion, previously buried pipelines can be exposed due to these dynamics. The existing analysis support technology for pipeline river crossings needs to be modernized and updated, and a two phase project has been initiated. Phase I, beginning in 2017, will investigate the software methodology including hydrodynamic loading, screening for allowable free spans and Vortex Induced Vibration (VIV) fatigue loading. The results will be compared with the state of the art formulations to validate and select the improvements to be included in the new software. Phase II, planned for 2018 will modernize the existing River- X program, include the improvements and validate the software.
- For the Subsea aspect of Design & Construction, two new projects are being initiated.
 - Subsea Pipeline Construction using Mechanical Connectors. These connectors are now used successfully in deep water drilling and can offer significant cost and time benefits if proven usable for other pipe joining applications. This project will determine whether mechanical connectors can be used as an alternative to welding for subsea pipelines, risers and other subsea pipe joining needs.

- Ultra Deep Water Pipelines. Offshore deep water exploration and production has so far been limited to depths up to about 10,000-ft due both to development costs and technological limitations. This project will evaluate the technology gaps for design and installation of pipelines at these depths, and the limitations on the design and installation of larger diameter pipe for a given water depth. This research will comprise several phases. The first phase now underway will identify and characterize the technology limits, and outline developments that address these limits.

Integrity & Inspection

Eight new projects in the Integrity & Inspection Committee that will start in 2017 to address key needs in non-destructive evaluation and integrity management are outlined below. These augment a number of active projects in the 2016 portfolio that will continue into 2017.

- Assess and develop NDE technology capabilities and qualification for near-surface hard spots, with potential deployment to steel mills, handheld devices, and ILI tools. Testing will be conducted using samples that have already been donated and are located at PRCI contractor and TDC locations.
- Evaluate NDE technologies to manage difficult-to-inspect pipelines/piping by providing quantitative performance evaluation of smart pigging tools. This project leverages the recently constructed liquid loop at the Technology Development Center with modifications to simulate difficult- to- pig pipelines/piping configurations.
- Develop a procedure and analysis methodology specific to NDE crack depth sizing performance validation for multiple ultrasonic technology techniques used to establish actual crack depths for PRCI reference standards and ILI performance verification.
- Further enhance integrity assessment of difficult-to-inspect pipelines by evaluating select areas using high resolution NDE. This research will build on previous work and seek out opportunities for field validation where remaining life from partial inspection process can be compared with remaining life from ILI or Hydrotest.
- Evaluate ILI crack tool reliability and performance evaluation through the re-examination of more recent inspection results. This work will provide operators with improved statistical models that consider the possibility of systemic uncertainties when measuring performance of in-line inspections for cracks.
- Validate the use of equipment to determine in-situ pipeline material properties in tandem with in-ditch material characterization techniques to demonstrate through blind trials the capabilities of these new technologies. This project will demonstrate the field performance of these approaches and introduce them to regulatory authorities to support pipeline Integrity Verification Process initiatives.
- Investigate the applicability of magnetic flux leakage to inspect oil & gas pipeline pinhole defects. Pull-through tests, field dig verification and sampling analysis will be used to create a sizing model. An optimized practice will be developed by comparing the gap between MFL tracks, sampling frequency, intensity of magnetic field, and other parameters.
- Enhance the integrity assessment of crack colonies with the aid of NDE advances including EMAT and Ultrasonic Imaging. This research will develop the processes needed to increase

the reliability and accuracy of predicted failure pressure calculations for SCC colonies based on EMAT-provided measurements, as well as in the ditch measurements. This work will also identify opportunities to improve EMATs and Ultrasonic technologies, as applicable.

Measurement

New work to be performed in 2017 by the Measurement Technical Committee includes:

- Additional assessment of upstream effects on ultrasonic meter performance
- Assessing the abilities of static mixers to provide a representative liquid sample
- Performing a gap analysis for liquid volume provers
- An assessment of ultrasonic noise reduction techniques to minimize interference with ultrasonic meters
- An assessment of a compact ultrasonic meter as a potential replacement for rotary meters
- Assessing sulfur condensation in pressure reduction equipment
- Assessing critical measurement issues associated with emerging gas supplies

Surveillance, Operations & Monitoring

New work to be performed in 2017 by the Surveillance, Operations & Monitoring Technical Committee includes:

- Additional development and full-scale validation of a polymer absorption sensor (PAS) cable-based liquid leak detection system
- Continued development and validation of a small methane/ethane leak detection system for use on handheld and small UAS platforms
- Evaluation of Current ROW Threat Monitoring, Applications and Analysis Technology to provide an understanding of the field data that needs to be acquired to drive threat reduction and to determine the applicability of current technology for threat mitigation.
- Field Testing of Distributed Acoustic Sensing (DAS) Technologies for in-situ detection of small leaks from liquid pipelines.

Underground Storage

Storage Field Integrity remains the primary focus of the Underground Storage Committee, with work generally directed at asset Integrity and risk assessment. Key projects for the 2017 program include:

- The continuation and expansion of a project to review and demonstrate Methane Emission Quantification Techniques for Storage Facilities



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FOR the global pipeline industry and those who have an interest in it:

Members vote for research projects most relevant to their organizations, so projects truly reflect the industry's priorities. The results provide intelligence allowing the industry to continue reducing risks from and to pipelines.



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