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FINAL PROJECT REPORT

CALIFORNIA NATURAL GAS PIPELINE ASSESSMENT: IMPROVING SAFETY BY ENHANCINGASSESSMENT AND MONITORING TECHNOLOGY IMPLEMENTATION

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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California Natural Gas Pipeline Assessment: Improving Safety by Enhancing Assessment and Monitoring Technology Implementation is the final report for the California Natural Gas Pipelines: Improving Safety through Enhanced Assessment and Monitoring Technology Implementation project (Contract Number 500-10-050), conducted by Gas Technology Institute (GTI). The information from this project contributes to Energy Research and Development Division's Energy Systems Integration Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

This project focused on providing a technology review of natural gas transmission pipeline assessment and monitoring technologies that are in use in California by pipeline operators, were available but not currently in use, or were emerging in the market. The primary goal of the project was to develop an implementation plan for pipeline assessment and monitoring technologies. The implementation plan was to recommend specific technologies and actions necessary to implement them in a timely and cost-effective manner. To accomplish this goal, the implementation plan was to also include recommendations for deploying currently available technologies, recommendations for developing selected emerging technologies, as well as recommendations for developing new technologies to meet outstanding gaps.

The secondary goals were to 1) identify technologies among those that are commercially available that are not in use, but could or should be; 2) identify emerging technologies that could quickly be moved to commercial availability; and 3) recommend how to leverage and optimize the use of the advanced metering infrastructure installed or being installed within California. The implementation plan shows how the selective development of technologies through the use of three separate, but linked, phases conducted in parallel, and operated under the existing program opportunity notice process, will address the primary and secondary goals. These development efforts focus on addressing each of the root causes that have resulted in death, injury, and/or property damage from pipeline incidents.

Keywords: Transmission, pipeline, assessment, implementation, plan, natural gas, technology

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EXECUTIVE SUMMARY

This document is the final report for the project "Natural Gas Pipeline Research – Best Practices in Monitoring Technology." The project focused on providing a technology review of natural gas transmission pipeline assessment and monitoring technologies that are in use in California by pipeline operators (Task 2), were available, but not currently in use (Task 3) or were emerging (Task 4), with the goal of developing an implementation plan presented in the Task 5 report.

Chapter 1

Chapter 1 reviews the project goals with the primary goal being the development of the implementation plan for the California Energy Commission. This plan could include laboratory and field-testing of new technologies, as well as further development of emerging technologies. The implementation plan was to also include a testing and deployment strategy for currently available technologies, recommendations for developing select emerging technologies, as well as recommendation for developing new technologies to meet outstanding gaps.

Included in that primary goal to develop an implementation plan were the secondary goals of 1) identifying quick "wins" within the set of commercially available technologies that are not in use, but could or should be (detailed in Chapter 3); 2) identifying emerging technologies that could quickly be moved to commercial availability; and 3) leveraging and optimizing the use of the advanced metering infrastructure installed or being installed within California (described in Chapter 4). The implementation plan shows how the selective development of technologies through the use of separate, but linked programs operating under the existing program opportunity notice process will meet the primary and secondary goals of the projects, while focusing the efforts of the Energy Commission on developing and deploying technologies that address each of the causes that have resulted in death, injury, and/or property damage from pipeline incidents.

Chapter 2

The first technical task was to conduct a comprehensive review of the technologies currently in use by the transmission pipeline operators. To ensure consistency throughout data gathering, it was necessary to establish what each operator considered a natural gas transmission pipeline. With some minor variations, California pipeline operators consider a pipeline to be transmission when operated at a pressure of 20 percent or more of the specific minimum yield strength other than a gathering line that transports gas to a customer or a storage facility.

Interviews were used to gather the information, using a guideline provided to each operator before the interview along with a summary of the technical scope of work of the project. Interviews with each company included a cycle of two or more sessions. The first session(s) captured the comments in draft form. These were provided to the operator for review, comment, and clarification, and then a follow-up session was conducted to ensure that the information was correct and to inquire if there was any additional information that had not been identified.

Early in the investigation, it was clear that the subject matter experts for each operator developed and maintained an integrity management program to ensure the safe operation of the pipeline network specific to the needs of their system based on the characteristics of their system and the technologies available. Each transmission pipeline operator is fully aware of the federal integrity management program requirements. The operators realize that an integrity management program is a continuous improvement process that recognizes technologies used to ensure that the safety and reliability of managing pipelines improve constantly. The operators were also keenly aware that the requirements do not represent a "one-size-fits-all" mandate, but rather provide the opportunity for subject matter experts to be involved throughout the program to develop and maintain a program specific to the needs of each operator. Pipeline systems varied in terms of miles of pipe, pipe size, age of construction, construction materials, operating pressures, control systems, communications capabilities, ability to inspect, environmental concerns, population densities encountered, and other factors. Not every technology is appropriate or provides value in every instance.

The technologies currently in use were summarized and placed in 1 or more of 11 technology categories. In addition to identifying the assessment and monitoring technologies in use, information was captured on the technology needs or gaps from the operator's perspective.

Chapter 3

The second technical task built on the information obtained during the review of technologies currently in use, resulting in a catalogue of commercially available technologies. The catalogue included those technologies currently in use in California, as well as those that could be used in California but were not due to lack of widespread use, as well as it being unknown or unproven.

This task also included the development of a gap analysis, which brought together multiple data collection efforts that included interviews, literature reviews, Internet searches, brainstorming sessions, and a workshop. Each effort provided information on the needs, gaps, and/or concerns between the currently practiced pipeline integrity assessment and monitoring technologies and those currently available for use, but not being used due to operational or regulatory barriers. The gap between the currently practiced pipeline integrity assessment and monitoring technologies and those currently available for use provided a pathway to identify opportunities to improve the assessment, monitoring, and integrity management program of the California pipeline network. Once the opportunities were identified, a three-level relative ranking process was used that recognized the sense of urgency to identify immediate opportunities by taking into account impact, value, timeliness, and feasibility. The three areas considered to be of the highest immediate value, feasible and able to make an immediate impact included:

- Right-of way-encroachment and excavation damage prevention.
- Alternative inspection technologies primarily directed at an alternative to hydro testing, in which the evacuated pipeline is pressurized with water.

- Education.

Additional opportunities were also identified that would further enhance pipeline assessment, monitoring, and safety, many of which are within the category of deployable within the next 12 to 24 months. These ready to deploy, or near ready to deploy, technologies that address technical needs in tracking and traceability, data collection and communications, risk modeling and incident prediction, internal and external assessment and inspection, and detection of pipeline leaks or ruptures. In the majority of instances, the technology is commercially available or in the final stages of becoming commercially available, with some level of field demonstration or verification of capabilities being warranted.

Chapter 4

The third technical task focused on identifying and prioritizing emerging technologies to enhance pipeline integrity that could be developed and implemented within two to four years, based on technical merit, applicability, reliability, cost-effectiveness, and degree of enhanced safety. The efforts of this task were to place special emphasis on developing a strategy to integrate the use of the advanced metering infrastructure communications backbone, currently being installed or enhanced in California. Through connecting pipeline monitoring sensors to the existing metering network, the costs associated with transmitting data to pipeline operators can be lowered. This emphasis would help optimize the value of the advanced metering infrastructure system and the performance of the pipeline monitoring and safety technologies identified or developed for implementation.

Every development of an emerging technology for pipeline integrity assessment and monitoring shares the common thread where there is the recognition of the need or gap, which may be initiated at any level within an organization. The need or gap may arise due to an operational, regulatory, financial, or other item of concern. The basis for pursuing a solution may be to improve safety, reduce cost, improve efficiency, replace outdated tools or techniques, address ergonomic issues, or leverage and optimize the capabilities embedded in a newly created or enhanced technology. Regardless of the type of need or rationale, an emerging technology will only become commercially available and termed to be used and useful if it is proven and accepted with full support from the pipeline operator, the regulator, and the manufacturer.

In addition to the challenge of the need to be proven and accepted, the development of a new or emerging technology is generally viewed as being expensive and time-consuming. Due to the challenge of cost, the majority of technology development of interest to the natural gas industry is undertaken through a collaborative approach. Collaboration allows funds to be leveraged, ideas vetted, and mutually beneficial characteristics identified to optimize development of the technology, ensuring that the needs or gaps are met in the most cost-effective manner possible. Another avenue for funding to develop new or emerging technologies of interest to the natural gas industry occurs through cooperative efforts with a government agency. As with the collaborative industry approach, the need to show value and share the cost is a key to the successful development and deployment of a technology. The final avenue for technology development is through the efforts of a single entity or private industry; however, unless there

is a specific advantage to the ownership of the intellectual property, this path is a less likely alternative. Should the private development path occur, the development effort would typically not be known until the technology is nearing commercialization.

A wide variety of programs from collaborative research and development organizations, along with those from the primary government agency involved in developing pipeline integrity assessment and monitoring technologies for the natural gas industry, were reviewed to identify the emerging technologies included in this report.

The emerging technologies, techniques, methods, and tools recommended for consideration by the Energy Commission were a subset of those, which were identified through a review of the ongoing technology development efforts to address the high priorities among the challenges listed above. Each of the recommended technologies could be implemented within four years. The recommendations were organized using a technology development strategy built on four strategic elements.

1. Asset life-cycle management – "What's where" – technologies provide an efficient set of capabilities to know what you have and where it is located.
2. System communications and control include emerging technologies to create or enhance the capabilities to communicate and control the system.
3. System monitoring and assessment illustrate the technologies needed to assess and monitor the system
4. Overarching issues capture a variety of needs and recommended activities that span the entire integrity management process

In addition to the description of the emerging technologies recommended under each of the strategic elements, an emerging technology development roadmap was provided, which summarizes the 47 projects or collaborative research and development programs recommended for consideration by the Energy Commission under the respective program areas that are associated with each strategic element. The roadmap showed each project on a development timeline, indicated the projects status (new, proposed or ongoing), the organization that is or will be controlling the work effort and the recommended priority (high, medium or low).

Chapter 5

The implementation plan brought together information from the three technical tasks described above that were used to effectively capture the current status of natural gas pipeline assessment and monitoring technologies used in California, compare those technologies to the full range of commercially available technologies, and then identify emerging technologies that had the potential to improve the integrity management process.

The implementation plan focused the approach from the broad area of pipeline assessment, to a technology development approach directed at addressing the causes of pipeline incidents that lead to death, injury, and/or property damage. The basis for this recommended approach is to focus the efforts of the Energy Commission on developing and deploying technologies that

would have the greatest potential to prevent incidents, reduce the consequences should an incident occur, and improve response time. The approach recommended maintains this focus, while recognizing that there are considerable parallel efforts to improve best practices, update processes and procedures, and limit right-of-way encroachment. Others are actively and effectively addressing these solutions.

The identification of causes comes from an assessment of past pipeline incidents as documented by the National Transportation Safety Board. The assessment started with a review of the 114 National Transportation Safety Board Pipeline Accident Reports from 1969 thru 2012. By focusing on incidents on natural gas transmission pipelines that resulted in death, injury, and/or property damage, five major causes emerged.

Causes

The top five major causes for pipeline incidents resulting in death, injury, or loss of property as determined by the National Transportation Safety Board can be summarized as:

- Failure to detect an existing defect. A defect may be the result of corrosion (internal or external), cracks dents or gouges, defective welds, or other anomalies.
- Poor data and record keeping over the life of the asset. This includes the full range of data from the time the pipe or appurtenance is manufactured, through construction and installation to operations and maintenance activity.
- Poor use of the data and records, resulting in a lack of awareness of the presence or status of facilities, as well as poor or low value analysis
- Failure to detect, locate, recognize, and respond to a leak or rupture in a timely basis
- Poor response or lack of a coordinated response to an incident

Damage Reduction Groupings

The incident causes identified above were placed in one of three damage reduction groupings that were believed to most strongly influence the reduction of death, injury, or property damage. This summary is stated below in the form of areas in need of improvement.

Prevention of Failure

1. Improve the capability to detect existing defects that may have been the result of manufacturing, construction, or postconstruction events.
2. Improve the records for the system from the point of manufacture through construction to operations and maintenance including inspections.
3. Improve analysis including data integration and modeling.

Mitigation of Consequences

4. Improve the capability to detect, locate, and react to leaks/ruptures.

Improvements in Response

5. Improve information transfer and emergency response and coordination.

The recommended implementation plan consisted of a three-phase program with each phase administered concurrently. A concurrent three-phase approach is recommended to focus the resources of the Energy Commission, thereby maximizing the potential to meet or exceed the Energy Commission goal of deploying technology within a two- to four-year time frame.

Phase 1 consists of the successful completion of the project(s) to be initiated based on the Energy Commission solicitation of project proposals under PON 12-505. This accelerated effort to develop pipeline assessment technologies was made possible as a result of recommended areas for technology development provided by GTI and UC Berkeley early in their respective projects.

Phase 2 consists of the Energy Commission actively participating in developing the emerging technologies as recommended in the Task 4 report (described in Chapter 4). The Task 4 report included summaries of 47 technologies in various stages of development that included a recommended level of involvement by the Energy Commission, along with a timeline and a priority.

Phase 3 consists of a series of programs to be administered concurrently using PONs to address each of the five major causes of pipeline incidents.

The implementation plan assumed that Phase 1 efforts were underway and that Phase 2 efforts could be initiated by the end of the second quarter of 2013. It was recommended that the creation and issuance of PONs to address the causes described in Phase 3 occur in parallel with the Phase 1 and 2 efforts, with the first round of PONs being issued no later than the third quarter of 2013. The timing of the individual projects within each program will be established based on the scope of work of each approved and contracted project.

A commitment of dedicated resources by the Energy Commission will be required to complete all three phases of the recommended three-phase implementation plan within the specified time frame of two to four years. Completion of Phases 1 and 2 are attainable, given that PON 12-505 is already underway and the effort associated with the recommended involvement of the Energy Commission in the various emerging technology development activities could be accomplished without a formal PON process. The anticipated deliverables of Phase 1 and the selective participation by the Energy Commission in the ongoing and new projects recommended in the Phase 2 effort could be directed to provide meaningful technologies to address the causes that serve as the core for Phase 3.

The concurrent administration of Phase 3 with Phases 1 and 2 presents the greatest challenge. Ideally, equal emphasis should be dedicated to addressing each of the five causes described under Phase 3 of the implementation plan. However, it is reasonable to assume that either financial resources, staffing or both may be limited. To optimize the potential for meaningful results from Phase 3 it is recommended that the highest priority be directed at the enhancement or creation of technologies that would improve the capability to prevent a pipeline failure. Should resources be available to go beyond the development and deployment of failure prevention technologies efforts should be dedicated to improvements that would mitigate the

consequences should a failure occur. Of the three efforts to address causes, the lowest priority would be the improvement of response to an event.

Benefits to California

The overall status of natural gas pipeline inspection technologies was assessed, and those that will provide the most benefits to California's natural gas pipeline integrity management practices were identified. The catalogue of available technologies provides operators a valuable reference in selecting the best inspection technology to use on the pipelines they manage. Currently commercial, as well as emerging, technologies that can meet state assessment and monitoring needs were identified, and a plan was developed to implement these technologies in state natural gas pipeline infrastructure. Through providing these valuable resources to pipeline operators in California, the safety of the natural gas infrastructure can be maintained efficiently.

CHAPTER 1: Introduction

1.1 Goals

The primary goal of the project directed Gas Technology Institute (GTI) to develop the Implementation Plan (Plan) presented in the Task 5 report and described in Chapter 5 for the California Energy Commission (Energy Commission). The Plan was to recommend specific technologies and the actions necessary to implement them in a timely and cost effective manner. This could include laboratory and field testing of new technologies as well as further development of emerging technologies. The Plan was to also include a testing and deployment strategy for currently available technologies, recommendations for the development of select emerging technologies as well as recommendation for the development of new technologies to meet outstanding gaps.

Included in that primary goal were the secondary goals of: 1) Identifying quick "Wins" within the set of commercially available technologies that are not in use but could or should be (presented in the Task 3 report and detailed in Chapter 3); and 2) The identification of emerging technologies that could quickly be moved to commercial availability as well as 3) How to leverage and optimize the use of the advanced metering infrastructure (AMI) installed or being installed within California (presented in the Task 4 report and described in Chapter 4). Information from each of these reports is included in the Plan showing how the selective development of technologies through the use of separate but linked programs operating under the existing Program Opportunity Notice (PON) process will address each of the root causes that have resulted in death, injury and/or property damage from pipeline incidents. (Appendices A and B provide a complete listing of acronyms and a glossary of terms, respectively, to assist the reader).

Early in the investigation it was clear that the subject matter expert (SME) for each operator developed and maintained an integrity management program (IMP) specific to the needs of their system based on the characteristics of their system and the technologies available. Pipeline systems varied in terms of miles of pipe, pipe size, age of construction, construction materials, operating pressures, control systems, communications capabilities, ability to inspect, environmental concerns, population densities encountered and other factors. Not every technology is appropriate or provides value in every instance.

1.2 Attributes for Success

There are three primary attributes that need to be addressed for any pipeline integrity management technology development effort to be successful. First, you have to know what you need and why you need it – the gap. Second, you have to know what the requirements or standards are that the technology has to satisfy to be acceptable for use. Third, you have to involve the three primary stakeholders that will make it a success – the operators, regulators and manufacturers. The following provides a summary of recommendations to increase the potential for successful pipeline integrity management technology development.

Demonstrable Benefits

Once a need or gap is clearly articulated the benefits of addressing that gap will be expressed in a variety of forms that can be categorized as either quantitative or qualitative. Both types of benefits are valuable with quantitative receiving the higher level of emphasis. Typically quantitative benefits are measured using a Net Present Value (NPV) model to document and measure the costs in comparison to the benefits. At the beginning of a technology development effort each type of benefit that addresses the gap is considered and the collection of benefits serves as the justification to proceed. Those technology development concepts that show a short term quantitative benefit versus cost coupled with qualitative benefits that may include reducing risk, improved environmental compatibility, improved safety or other items are given preferential consideration.

Recommendation

At times the technical capabilities and the product marketing are out of sync such that users unknowingly become part of the development cycle. It is recommended, due to the high level of sensitivity to ensuring a safe and reliable system, that the operators, regulators and manufacturers are aligned as to the merits of the technology and that prior to the advocacy for the adoption and subsequent dependence on any tool, technique or technology a full independent verification of capabilities takes place.

Regulatory Participation

The regulatory process and the pace of technology development follow very different timelines. In some instances the promulgation of new regulations creates a series of compliance challenges, in other instances the application of a newly developed technology may be prohibited due to regulatory limitations that did not anticipate the potential for advancements in certain areas.

Recommendation

Regardless of the current scenario, all future technology development and deployment should occur with full participation by the regulator agency to provide the standard of acceptance that will ultimately determine if the technology can become used and useful for the pipeline operator.

Operational Support

Almost by definition natural gas utility pipeline operators are inherently problem solvers with a conservative view toward the adoption of new technology. Any change includes a level of risk resulting in one or more operational barriers. Running in opposition to this conservative view is the recognition that technological advances are occurring constantly resulting in lower cost, faster, easier capabilities.

Recommendation

Early adopters and innovators are found throughout the industry, identify those early adopters that are willing to assist in focusing the development and deployment efforts and work with them to identify the operational barriers/gaps as well as the industries standards of acceptance.

Manufacturer Participation

It is a rare technology that survives without being commercially viable. The involvement of a manufacturer early in the development cycle is critical to the success of a product or service.

Recommendation

Involve one or more manufacturers early in the technology development cycle depending on intellectual property and right to use issues. The manufacturer will differentiate between "can you do it?" and "can you afford to do it?", in other words - Is there a market?

1.3 Task Reports and Workshops

In parallel with gathering data from the pipeline operators, which included a discussion of their respective Research and Development (R&D) programs used to summarize the technologies currently in use (presented in the Task 2 report and described in Chapter 2), GTI reviewed the programs of the three primary R&D organizations (GTI, Pipeline Research Council International (PRCI) and Northeast Gas Association (NGA)) involved in natural gas as well as the needs identified by Department of Transportation – Pipeline and Hazardous Materials and Safety Administration (DOT PHMSA), the primary federal agency involved in pipeline integrity management. In large part this review captured the operational and regulatory needs for assessing and monitoring natural gas transmission pipelines. To supplement these efforts GTI also reviewed the R&D programs of the Operations Technology Development (OTD) not for profit (NFP) a member-controlled partnership of natural gas distribution companies formed to develop, test, and implement new technologies, Sustaining Membership Program (SMP) a collaborative R&D program managed and performed by GTI, American Gas Association (AGA) Foundation and the Interstate Natural Gas Association of America (INGAA) Foundation. Each of these industry organizations are involved with research that includes integrity management. Finally, the efforts included detailed literature reviews, reviews of meeting agendas and minutes, interviews with SME's internal and external to GTI, discussions with University of California at Berkeley (UC Berkeley) and two workshops, one conducted by GTI and one conducted by the Energy Commission, all of which assisted in the identification of currently available as well as emerging pipeline assessment technology.

Technologies identified as currently available were summarized in the Task 3 Report through the use of a catalogue (Appendix C). Task 3 also included a presentation of the needs that could be immediately filled as well as an identification of the gap between current practices and technologies known to be available.

Emerging pipeline integrity assessment and monitoring technologies were reviewed and summarized in the Task 4 report. This summary included a description of each emerging technologies as well as an Emerging Technology Development Roadmap (Appendix D) which summarizes the 47 projects or collaborative R&D programs recommended for consideration for participation by the Energy Commission.

In addition to the emerging integrity assessment and monitoring technologies identified during the course of this project for use in the natural gas industry, consideration was given to technologies used in related industries concerned with the integrity of pipelines used to

transport various products or process fluids. One example of a related industry would be liquid pipelines used to transport oil, gasoline or propane. Another example would be the power generation industry where the integrity of high pressure steam and water lines are of concern.

The efforts of Tasks 3 and 4 clearly illustrated the relative nature of the term "new". A technology may have been used for years in the liquid pipeline industry but due to the differences in the commodities being moved and the challenges of applying it to natural gas the introduction of that technology would be considered new, others might consider it as emerging. It was noted that the "newness" of a technology is in the eye of the beholder. To avoid confusion the terms emerging and new were merged, and any technology included in this report that is not considered commercial is termed emerging and discussed accordingly.

The Plan provided a technology development approach focused on addressing the root cause(s) of pipeline incidents. It was recommended that the greatest immediate benefit would be realized by focusing the entire resources of the Energy Commission on the development of technology that focuses the approach from the broad area of pipeline assessment to a technology development approach directed at addressing the root causes of pipeline incidents. This recommended approach described a three phase program with each phase administered concurrently maximizing the potential to meet or exceed the Energy Commission goal of deploying technology within a 2 to 4 year timeframe. Phase 1 consisted of the successful completion of the project(s) initiated based on the Energy Commission solicitation of project proposals under PON 12-505. Phase 2 consisted of the Energy Commission actively participating in the development of the emerging technologies as recommended in the Task 4 report which summarized 47 technologies in various stages of development and included a recommended level of involvement by the Energy Commission, along with a timeline and a priority. Phase 3 consisted of a series of programs to be administered concurrently using PONs to address each of the five major root causes of pipeline incidents.

The recommended approach in the Plan will focus the efforts of the Energy Commission on the development and deployment of technologies that would have the greatest potential to prevent incidents, mitigate the consequences should an incident occur and improve response time. The recommended approach recognizes that efforts to improve best practices, update processes and procedures and limit right-of-way encroachment are being actively and effectively addressed by others.

CHAPTER 2: Summary of Task 2 Report

The goal of this task was to perform a comprehensive review of the current state of technology being used in California to manage natural gas transmission pipeline integrity and safety.

To accomplish this goal, it was first necessary to become familiar with the natural gas transmission system in California to identify, and establish a contact with, each of the natural gas transmission pipeline operating companies. Once a contact was established, the project concept and requirements were introduced to the company representative(s) through the use of a condensed version of the technical scope of work (Appendix E) along with an interview guide (Appendix F) that would be used to collect the data for the baseline technology assessment.

The starting point to ensure consistency of discussion and responses for the baseline assessment of technologies used in California was to establish what each operator defined as natural gas transmission. The overarching approach used by the operators to define a natural gas transmission pipeline was to use the PHMSA definition from 49 Code of Federal Regulations (CFR) Section 192.3(2) – Transmission pipeline means a pipeline that operates at a hoop stress of 20 percent or more of Specified Minimum Yield Strength (SMYS) other than a gathering line that transports gas to a customer or a storage facility. Minor variations or extension to the PHMSA definition added criteria such as a pipeline operated at a pressure above 60 psig and/or at or greater than 20% SMYS, or serving a large customer (total demand of 20,000 MMcf/d or greater) upstream of the Local Distribution Company (LDC) or piping used to transport gas within a storage field for purposes of well injection or withdrawal and is not a gathering line.

Metrics are an inherent part of an IMP used for trend analysis, establishing limits and relative risk in data integration software, for preventative and mitigative assessment, to adjust the frequency of testing etc. Depending upon the specific issue an operator may utilize a wide variety of tools, technologies and methods for data gathering and integration such as: risk modeling, in-line inspection (ILI), investigative excavation, gas quality monitoring, hydro-testing, aerial and/or ground based patrols, additional signage and enhanced communications to name a few. Past incident history is considered along with records of corrosion control, continuing surveillance, patrolling, maintenance and internal inspection.

Each of the transmission pipeline operators is fully aware of the IMP requirements from 49 CFR Part 192. During each of the interviews, the operators emphasized that the technologies and processes used to ensure the safety and integrity of the pipelines were used in accordance with the appropriate subpart of Part 192 and by reference the American Society of Mechanical Engineers standard - Managing System Integrity of Gas Pipelines (ASME B31.8S-2004). The operators realize that an IMP is a continuous improvement process that recognizes technologies used to ensure the safety and reliability of managing pipelines improve constantly. The operators were also keenly aware that the requirements do not represent a “one-size-fits-all” mandate, but rather provide the opportunity for SME’s to be involved throughout the program to develop and maintain a program specific to the needs of each operator. Many of the operators are responsible for natural gas pipelines in other states or other countries. With that broad base of experience comes familiarity with various commercially available integrity

management technologies and a comprehensive understanding of which technology is appropriate to be applied in a given situation or for a given environmental setting. Not every technology is appropriate or provides value in every instance. For example, using vegetative surveys as an indicator of a potential leak in a desert environment would be non-productive or using an Electromagnetic Acoustic Transducer (EMAT) inspection or investigative excavations on newly installed pipe with high performance coating systems would not be advised as the threat from Stress Corrosion Crack (SCC) is low. In both instances there is full awareness of the technology and the inherent value of its use; however, the use of the technology is not necessarily warranted in every instance.

2.1 Threats to Pipeline Integrity

The tools, techniques and methods each operator in California uses to identify and evaluate all potential threats to pipeline integrity within their IMP were captured under one or more of eleven categories. For purposes of an IMP the four types of threats include:

- Time dependent threats such as internal corrosion, external corrosion, and stress corrosion cracking;
- Static or resident threats, such as fabrication or construction defects;
- Time independent threats such as third party damage and outside force damage; and
- Human error.

2.2 Technology Categories

The eleven categories used to capture the technologies along with an indication of which of the four types of threats addressed by the technologies in each category are described below:

1. Internal and External Assessment and Inspection Methods

Internal and external assessment and inspection methods cover a broad range of technologies that have the capability of identifying and evaluating threats in each of the four types. In-line inspection tools are used for threats from internal and external corrosion, changes in geometry from third party damage or construction damage, dents or outside forces as well as fabrication or construction defects. Direct assessment is used for internal as well as external inspection to detect corrosion. Visual inspection along with foot and mobile patrols are used along with leak inspections to ensure no changes have taken place either to the pipe, the right-of-way, the characterization of the High Consequence Area (HCA) or to alert the operator to a past third party damage incident.

2. Long-Term Condition Monitoring Techniques

The technologies used for long term condition monitoring provide an indication of change based on a comparison to previous results or to established limits or criteria. Results are used for trends analysis and an evaluation of risk. Threats addressed by this category of technology are typically time dependent such as corrosion, but may also include time independent threats resulting from third party damage or outside forces.

3. Risk-Modeling and Incident Prediction Tools

Risk models and incident prediction tools are heavily dependent on the quantity and more importantly the quality of the data available. The data collected and integrated from the tools and techniques described under other categories provide the basis for trend analysis and the ability to compare normal operations to changes in the physical or operating aspects of the pipeline system suggesting the need for additional assessments, a review of previous assessments or mitigative activities.

4. Right of Way (ROW) Encroachment and Excavation Damage Prevention

Mechanical damage caused by unauthorized third-party excavations is the most significant threat to pipeline safety having the highest probability of occurrence and the highest probability of damage. Threats of this type are described as time independent or may fall under human error. One operator has identified third party damage as a 74% risk to pipeline operations. Integrity management damage prevention programs provide various ways to reduce and mitigate the risk.

5. Detection of Pipeline Leaks and Ruptures

Leaks are a measurement of direct integrity and are captured in an integrity management program using the metric of leaks per mile. Data from subsequent leak surveys are then compared to previous results as a measure of change in leaks per mile. Leaks are classified based on quantity and severity, and where clusters of leaks are detected operators are informed to ensure an appropriate and timely response.

Line ruptures are detected based on the ability to detect a rate of change in pressure. When a large pressure drop is detected across a valve or over a designated time period line rupture control systems activate resulting in the automatic or remote closure of selected valves. The typical threat addressed with the detection of leaks and ruptures are time dependent due to corrosion or time independent due to third party damage or outside forces.

6. Remote Stress/Strain Analysis of Pipelines

Pipeline stress and strain are typically the result of some form of ground movement such as landslides, earthquakes, and slope movement or due to displacement at a crossing location. Stress and strain monitoring may also occur at the location of a wrinkle bend, where strain relief was recently performed or at receipt point to ensure proper pressure is maintained. Stress and strain analysis is performed to determine if sufficient change has occurred to warrant the activation of auto close devices or if other mitigative measure are appropriate. The typical threat addressed with remote stress and strain technologies are time independent threats from outside forces.

7. Tools, Techniques, and Data Analysis Methods Utilized in Integrity Management Programs

Operators use various methods to capture data and ensure the integrity of its pipeline. Threats addressed in this category are of all four types.

8. Nondestructive Examination and Analysis Methods

At the time of an excavation a variety of non-destructive techniques are used to check for environmental characteristics and physical condition. Data is integrated and analyzed from a variety of sources such as ultrasonic testing, magnetic particle testing for stress corrosion detection, holidays in the coating to check for the condition of the coating, soil samples to understand corrosivity of the soil, measurements of cathodic protection (CP) to understand the level of protection and corrosion mapping techniques to size and analyze remaining strength. At the end of the assessment the pipe is re-coated if necessary and special backfill requirements are followed using an engineered backfill. Non-Destructive Testing (NDT) is among the methods captured in Category 1 above, additional details on the technologies mentioned earlier are mentioned under this category along with the listing of additional technologies. Threats addressed by technologies in this category are primarily time dependent such as those from corrosion and time independent such as those from third party damage.

9. Automated, Semi-automated, and Manual Methods for System Shutdown

The technologies in this category would include a Supervisory Control and Data Acquisition (SCADA) system and/or a trained system operator, dispatch personnel with vehicle tracking capability, valves ranging from manual to automatic that may fully close or throttle back to a reduced flow, and the ability to use an Incident Command System as warranted. The threats addressed through the use of these technologies would include all four types.

10. System Modeling of Incident Responses and Shutdown

The techniques and methods used for system modeling, incident response, and shutdown include a variety of preparatory and mock exercises, drills, pre-planning for events and establishing procedures to be used in case of an emergency. The technologies ultimately used for purposes of a response are similar to those described in the previous category and would include a SCADA system and/or a trained system operator, dispatch personnel with vehicle tracking capability, valves ranging from manual to automatic that may fully close or throttle back to a reduced flow and the ability to use an Incident Command System as warranted. The threats addressed through the use of these technologies would include all four types.

11. Data Collection and Communication Technologies

Data collection and communications technologies provide the means to monitor control and operate the system. The techniques used for data collection vary widely in the frequency of collection, the accuracy and precision exercised and the systems used to communicate, integrate and analyze the data. Communications techniques and technologies to relay the data from the field to the back office vary widely as well. All modes of communications are put into practice ranging from the most sophisticated company owned point-to-point microwave or satellite systems to notations on paper. Once provided and recorded at a central location software packages are used for trend analysis, work management, integrity

compliance, mapping and operations. The threats addressed by the data collected and communicated include all four types.

2.3 Technology Needs and Gaps – Operators Perspective

Accompanying the interviews to capture the technologies and processes currently in use in California, was the effort to capture information that would help to characterize needs or gaps in technology from the operator's perspective. The potential needs or gaps were captured in one of four scenarios:

- Technologies that had been used at one time but were no longer being used due to:
    - No longer available?
    - Determined to be ineffective?
    - Was there a gap in the capabilities? If so, what was that gap?
    - Difficult or dangerous to use?
    - Replaced by a method that became the industry standard?
    - No longer allowed by regulation?
- A commercially available technology used elsewhere that may be appropriate for use in California
- A new or replacement technologies under development or
- An identified need or gap where a technology would need to be created or enhanced

The responses from operators to the above questions are summarized below.

Technologies No Longer Being Used

The typical reason for making a change was due to the technology becoming obsolete and no longer cost effective to maintain or there was no vendor support. The inspection tools have evolved from low resolution to high resolution to combination high resolutions. Generally, the latest technologies available are used.

- Some of the tools are not used because the situation that would obligate the need hasn't occurred
- Guided Wave ultrasonic technology (UT) was approved for use in the past as a standalone integrity assessment method under "Other Technology." While still allowed by the code, regulatory restrictions have made widespread use of the method infeasible/impractical
- Remote Terminal Unit (RTU) protocols, technologies moved on, SCADA has evolved
- Not using weight loss coupons today, but looking to going back to using weight loss coupons in combination with electron microscopy (EM) coupons
- Pressure monitoring – moving away from link and lever paper charts, toward more electronic devices, reducing the potential for human error, also vaults fill with water at times, data archiving is easier with electronics, also allows for gathering the data remotely
- Leak survey tools – changed the tool that was used ex. OVA – 88 provided by one provider, now considered obsolete, want to go to an intrinsically safe device (no flame)

Commercially Available Technologies Used Elsewhere

- OSISOFT PI software
- PIPETEL – Explorer II, self-propelled robot that used eddy current technology and can be used on non-piggable lines
- 6-8 inch tool that can be inserted through a hot tap for In-Line Inspection (ILI). The tool is a self-propelled and uses eddy current to inspect non-piggable lines
- Larger tool 10-14 inch that uses magnetic flux leakage (MFL) also can be used on non-piggable lines
- Spiral MFL – ILI tool used to assist in determining long seam concerns. The spiral MFL turns the magnet to be oriented to a different plane so the system is capable of providing information that is other than just axial
- Geographic Information System (GIS) Replacement – increase our mapping and data information and integration by moving to a more up-to-date version of a commercially available software or moving from a "home grown" GIS to a commercially available GIS
- Online analysis tool for leak detection for SCADA
- Acoustic monitoring system for pipeline leaks or damage by third parties
- Light detection and Ranging (LIDAR) equipment – aerial leak detection technology – helicopter mounted device, conducting trials comparing it to ground surveys – differential absorption leak detection survey equipment
- EMAT inspection technologies to improve detection and assessment of stress corrosion cracking (SCC). The current SCC risk is primarily managed through hydro-testing. The near future capability will provide in-line inspection for SCC enabling defect management of SCC similarly to the management of corrosion features

Technologies Under Development

- PIPETEL – Explorer II
    - 20-24 inch tool for non-piggable lines available by the first quarter of 2012
- "ThreatScan" by General Electric (GE) is commercially available but needs further development. The technology is based on sound traveling on the pipe with sensor that are monitored 24 hours/day to tell when a pipe has been hit
- RSD X-Ray ILI Tool is a technology based on backscatter x-ray imaging being developed for internal inspection applications for both metallic and non-metallic pipe

Technologies Needing Creation or Enhancement

- Un-locatable facilities – standard instruments are not effective, use technology to help locate facilities that are un-locatable with current technology
- Leak survey technologies that would improve the techniques used today
- The use of fiber optic cabling for monitoring Pipeline ROW intrusion

- Using AMI for:
    - Real-time methane detection along some stretches of our larger pipelines
    - Increased system flow and pressure monitoring in real-time
    - Informational pipeline monitoring, and back-up (redundant path, emergency only) operation of selected valves

    - Providing a low cost approach to move the data
- Enhancement to LIDAR
- Crack sensor detectors – on the 24 inch PIPETEL tool
- Improve the value of EMAT technology using a needs assessment approach resulting in new capabilities
- UT – automated girth weld tool to inspect on a tether, inspects welds from the inside
- Development of Invodane's robotic in-line inspection tools for medium and large diameter pipelines that are un-piggable with conventional tools
- Development of alternative acoustic pipeline/ROW intrusion monitoring technologies
- Real time modeling systems to help develop new ways to control the pipeline utilizing an on-line analysis tool to model the system versus real-time data to gain intelligence and identify risks as they develop
- Replacement tool for the existing GIS – to include real-time monitoring, fundamental change to the data model and how the model is structured, software change plus the addition of analysis tools to allow the major enterprise tools to be integrated with the GIS to know the "what" and the "where"
- Develop a tool to accurately measure the length and depth of a crack while you're in the ditch
- Assessment of long seams and girth welds
- Develop a predictive performance based (proactive) modeling tool and integrate the data to be able to make an effective decision or have it direct you programmatically to where you should be concerned. This approach would provide a programmatic decision method rather than a prescriptive (reactive) method. The benefit of this type of improvement relates to the continuing search for efficiency improvements as well as to supplement human decision making. Note that such an approach will take at least one (and more likely several) assessment of the same pipelines to be effective. Significant experience and extensive data would be required to use the predictive approach
- Develop an industry database that collected the data from IMPs and make that data available to others providing a larger database that could be used for trend analysis and threat identification
- Low cost and low power consumption monitoring and communicating technology for remote applications to expand the SCADA data collection system
- Method to integrate the SCADA system with the GIS – define the point information once and be able to populate it with field data
- Mobile technology that provides field tablet for field employees to have real time data in the field, eliminate paper and provide a single point of entry to the databases

2.4 Recommended Next Steps from the Baseline Assessment

A subset of the technologies needing creation or enhancement as identified by some operators are in use by others, are in the final stages of development, or are being deployed by the R&D community. It was also noted that a lessons learned exercise where an open forum is provided for the operators would have immediate benefits as the technologies in use varied significantly between operators. Finally, a brainstorming workshop would result in an identification of

synergies as the conversations during the interviews identified that the needs and gaps expressed by one operator were also identified by one or more other operator(s). This identification of common needs would suggest that a facilitated collaborative approach using brainstorming techniques would help focus the investigative efforts on those needs having the greatest potential for widespread application. Based on this initial assessment the following was recommended:

- Conduct a workshop with two goals
    - Compare what each operator already does to find technologies, processes and methods that works for one operator and may work for others
    - Conduct a brainstorming session of needs and gaps

CHAPTER 3: Summary of Task 3 Report

The goal of this task was to assess all the available natural gas transmission pipeline assessment and monitoring technology that could be used in California, but is not currently being used because it is either: (a) ready for use but not widely used on a commercial basis, (b) unknown, or (c) unproven.

To accomplish this goal GTI was to:

- Identify immediate opportunities to improve the assessment, monitoring, and integrity management of the California pipeline network
- Rank these opportunities based on impact, value, timeline, and feasibility
- Catalogue all currently available pipeline integrity related technologies
- Clearly define which pipeline assessment and monitoring needs could be immediately filled with commercially available technologies
- Develop a gap analysis between the currently practiced or available pipeline integrity technologies and what is recommended to further enhance pipeline safety

The final deliverables for this task included a catalogue of available technologies and a gap analysis.

GTI's effort's to accomplish this goal, the identified requirements and provide the deliverables included:

- Interviews with SME's within GTI
- Interviews with external SME's
- Interviews with operators of pipelines in California
- Literature review
- Internet searches
- Brainstorming sessions with internal and external SME's
- A review of each technology to identify the strengths and weaknesses
- A review of each technology to determine the ability of each technology to communicate as well as assess the need for a capability of using the AMI backbone for communications and improved response
- Conducting gap analysis via a Pipeline Assessment Technology Workshop with representatives from the California pipeline operators, INGAA, PRCI and GTI

3.1 Catalogue of Available Technologies

The creation of the catalogue (Appendix C) of pipeline integrity assessment and monitoring technologies was viewed as the primary means of establishing a baseline from which a gap analysis could be developed. The catalogue included a fact sheet for each currently available technology which described:

- The category most appropriate for the technology among the eleven categories of technologies used for reporting

- The method by which the technology is applied – example internal inspection versus external
- A description of the technology
- The strengths of the technology
- The weaknesses of the technology, this is also useful for identifying potential needs or gaps
- The manufacturer(s) of the technology - a listing of specific manufacturers providing a technology is only provided when the overall number is limited to a few
- The utilities using the technology – a listing of specific utilities using a technology is only provided when the overall number is limited to a few
- A determination of the communications capability or whether communications is of value
- References indicating where additional information can be found

3.2 Gap Analysis

The gap analysis represented the culmination of multiple data collection efforts that included interviews, literature reviews, internet searches, brainstorming sessions and a workshop. Each of these efforts provided information on the needs, gaps, and/or concerns between the currently practiced pipeline integrity assessment and monitoring technologies and those currently available for use but not being used due to operational or regulatory barriers. The gap between the currently practiced pipeline integrity assessment and monitoring technologies and those currently available for use provided a pathway to identify opportunities to improve the assessment, monitoring, and integrity management program of the California pipeline network. Once the opportunities were identified a three level relative ranking process was used that recognized the sense of urgency to identify immediate opportunities by taking into account impact, value, timeliness, and feasibility.

3.3 Highest Value Opportunities

Three areas that were considered to be of the highest immediate value are feasible and would make an immediate impact included:

- ROW encroachment and excavation damage prevention
- Alternative inspection technologies primarily directed at an alternative to hydro testing
- Education

3.4 Additional Opportunities

In addition to these three areas considered to be of the highest immediate value, additional opportunities were also identified that would further enhance pipeline assessment, monitoring and safety many of which are within the category of deployable within the next 12 to 24 months. These additional technologies would complement an operator's IMP, improve tracking and traceability and/or reduce operating costs. These technologies are all available or nearing availability for use in California, but are not currently being used because it is either: (a) ready for use but not widely used on a commercial basis, (b) unknown, or (c) unproven. These ready

to deploy, or near ready to deploy technologies address technical needs in the areas of tracking and traceability, data collection and communications, risk modeling and incident prediction, internal and external assessment and inspection and detection of pipeline leaks or ruptures. In the majority of instances the technology is commercially available or in the final stages of becoming commercially available with some level of field demonstration or verification of capabilities being warranted. In the remaining instances where a technology is not commercially available the anticipated development to deployment cycle is as indicated in the two categories shown below.

12 Months to Deploy:

- Hand-held devices for field use
- Integration of field data immediately into a GIS
- Survey grade Global Positioning System (GPS) information without post-processing immediately available in a GIS
- Use of bar coding to optimize field data collection and automate data entry
- Use of radio frequency identification (RFID) tags to locate facilities and to collect and store field data for later processing
- Conduct a lessons learned and technology demonstration workshop
- Create an industry database as the first step toward the development of a predictive performance based (proactive) modeling tool

12 to 24 months to deploy:

- Upgrading and integrating GIS with various software such as work management, asset management, enterprise management, Stoner and/or SCADA
- Accurate measurement of crack length and depth in the ditch with transmittal to the back office
- Predictive performance based modeling and risk management tool integrated with an industry database to supplement human decision making
- Low cost methane detectors using a "fence post" approach along a right-of-way capable of operating remotely, detecting methane emissions in the 100 to 200 part per million (ppm) range and providing an alarm
- Tracking and work management software tool(s) for HCAs that would use publically available data along with aerial surveillance systems and be as accurate and reliable as "boots on the ground"
- Low cost, low power measuring technologies dispersed at smaller intervals than those currently in use to provide an accurate picture of the system in real-time. Deployment would be preceded by the verification of the AMI two-way communications and sensor capabilities which would include:
    - The existence of an AMI with redundancy and security in the areas where sensor deployment would take place
    - Full access to and inter-operability and security of the AMI communications system
    - A determination that the low cost, low power sensors under development have an operational and life cycle cost advantage over existing

technology that may require enhancement or modification to be compatible with the AMI communications system
    - Full inter-operability of the low cost, low power sensors under development
- Once verified, as described above, use the AMI system to create or enhance the ability to provide two-way communications, monitoring and control resulting in:
    - Redundant paths for data flow
    - Low cost approach for data collection and system monitoring capable of adding monitoring points and system control as new low cost/low power technologies are developed – Ex. ROW encroachment and excavation damage prevention, leak detection
    - Improved pipeline monitoring of flow and pressure in real-time
    - Improved operation of selected valves
    - Instantaneous identification of an issue or failure requiring pipeline shutdown

CHAPTER 4: Summary of Task 4 Report

The goal of this task was to identify emerging technologies to enhance natural gas transmission pipeline integrity that could be developed and implemented within two to four years based on technical merit, applicability, reliability, cost effectiveness, and degree of enhanced safety.

To accomplish this goal GTI was to:

- Recommend specific hardware, software, and practices that could be considered from a broad array of technologies including (but not limited to):
    - Hardware, sensors, software, and/or process solutions,
    - Land, air, and space (satellite) based platforms,
    - Robotics and internal inspection technologies,
    - Communication pathways through the smart energy grid such as wireless and SCADA networks, and
    - System automation, response, and simulation modeling techniques.
- Prioritize (by impact, feasibility, and timeliness) emerging technologies that could be developed to enhance pipeline safety, assessment, monitoring, and overall system integrity that could be implemented within four years.
- Place special emphasis on the development of a strategy to integrate the use of the AMI communications backbone, currently being installed or enhanced in California. This will optimize the value of the AMI system and the performance of the pipeline monitoring and safety technologies identified or developed for implementation.

Each recommended emerging technology was within or had successfully passed through the proof of feasibility stage of technology development. The majority of the recommended technologies had one or more operational or regulatory barriers to overcome before wide-spread use would occur. This evaluation was focused on technologies that were not commercially available and were viewed to have the potential for deployment in the next 1-2 years followed by those emerging technologies that were projected to require additional development prior to deployment.

Emerging technologies for pipeline integrity assessment and monitoring share a common thread recognizing that a need or gap has been identified. The source identifying that need or gap varies widely and may be initiated at any level within an organization. The need or gap may arise due to an operational, regulatory, financial or other item of concern. The basis for pursuing a solution may be to improve safety, reduce cost, improve efficiency, replace outdated tools or techniques, address ergonomic issues or leverage and optimize the capabilities embedded in a newly created or enhanced technology. Regardless of the type of need or rationale an emerging technology will only become commercially available and termed to be used and useful if it is proven and accepted with full support from the pipeline operator, the regulator and the manufacturer.

In addition to the challenge of the need to be proven and accepted the development of a new or emerging technology is generally viewed as being expensive and time consuming. Due to the challenge of cost, the majority of technology development of interest to the natural gas industry

is undertaken through a collaborative approach. Collaboration allows funds to be leveraged, ideas vetted, and mutually beneficial characteristics identified to optimize the development of the technology insuring that the needs or gaps are met in the most cost effective manner possible. Another avenue for funding to develop new or emerging technologies of interest to the natural gas industry occurs through cooperative efforts with a governmental agency. As with the collaborative industry approach the need to show value and share the cost are keys to the successful development and deployment of a technology. The final avenue for technology development is through the efforts of a single entity or private industry; however, unless there is a specific advantage to the ownership of the intellectual property this path is a less likely alternative. Should the private development path occur, the development effort will typically not be known until the technology is nearing commercialization.

A wide variety of programs from collaborative R&D organizations, along with the primary governmental agency, involved in the development of pipeline integrity assessment and monitoring technologies for the natural gas industry were reviewed to identify the emerging technologies included in this report. Each organization involved in the development of one or more emerging technologies included in this report is briefly described below.

4.1 Research and Development Organizations

Gas Technology Institute

GTI is the leading research, development and training organization addressing energy and environmental challenges to enable a secure, abundant, and affordable energy future. For 70 years, GTI has been providing economic value to the natural gas industry and energy markets by developing technology-based solutions for industry, government, and consumers. GTI's mission is to solve important energy challenges, turning raw technology into practical solutions that create exceptional value for our customers in the global marketplace. The objectives of the organization are to: 1) Expand the supply of affordable natural gas and renewable energy; 2) Ensure a safe and reliable energy delivery infrastructure; 3) Promote the clean and efficient use of energy resources; 4) Reduce carbon emissions to the environment. GTI also provides program management support to the Sustaining Membership Program, Operations Technology Development, NFP, Utilization Technology Development, NFP, and Emerging Technology Development Program.

GTI's Infrastructure Sector addresses challenges in unconventional gas production, pipeline and distribution integrity, and environmental footprint reduction—from down hole to the meter. The research and technical services of data and integrity management, infrastructure rehabilitation and improvements and breakthrough technologies organized under the Infrastructure Sector include the development and deployment of technologies to improve pipeline integrity assessment and monitoring.

A description of GTI's philosophy and approach to R&D for the natural gas industry can be found at the following website.
http://www.gastechnology.org/webroot/app/xn/xdb9ac.html?it=enweb&xd=gtihome.xml

Sustaining Membership Program

The SMP is a not-for-profit collaborative established in 1985 with the mission to build a strong technology base in natural gas delivery, energy utilization, environmental science and renewable energy; to create new, innovative solutions through "proof of concept" that address the most important industry needs; and to provide early-stage R&D that serves as the building blocks of subsequent commercial research efforts. R&D is a system of interconnected activities. SMP is the first step of this system. Members collectively leverage experience, expertise and funds to reduce risk and uncertainty of R&D to help push clean, safe energy solutions on a path toward future gains. SMP develops the technology through "proof of concept," the point at which the most promising technologies are continued through short- to mid-term R&D programs, implemented by organizations such as Operations Technology Development, NFP and Utilization Technology Development, NFP. Among the technology development areas of focus for SMP are those that address pipeline integrity assessment and monitoring, projects associated with this area of emphasis were considered for inclusion within the emerging technologies to be recommended. An overview of the SMP program can be found at the following website.
http://www.gastechnology.org/webroot/app/xn/xdb071.html?it=enweb&xd=2ProductsServices/2_1ContractRes/SMP/SMPHome.xml

Operations Technology Development, NFP

The OTD is a not-for-profit collaborative established in 2003 that now includes 23 member companies that operate natural gas infrastructure providing R&D responses that benefit the natural gas industry and its customers. In recent years, significant OTD developments have focused on pipe-inspection methods, sensor technologies, risk management, and other projects related to pipeline integrity. The OTD Board of Directors recently established four high priority areas for future technology development, three of those four are directly related to pipeline integrity management.

1. Develop alternatives to hydro-testing
2. Eliminate manual data collection
3. Develop inspection tools for integrity management

An overview of the OTD program can be found at the following website.
http://www.gastechnology.org/webroot/app/xn/xd1948.html?it=enweb%26xd=otd/otdhome.xml

Pipeline Research Council International

The PRCI was established in 1952, with the commitment and technical expertise of its members, PRCI continues to develop dynamic research programs devoted to identifying, prioritizing, and implementing the industry's core research objectives. As a result, PRCI has become a critical resource for all energy pipelines regardless of where they operate, how they operate, or the purpose of their operation. Unique among all pipeline research organizations, PRCI brings together leading pipeline companies from around the world to engage in a collaborative process that is truly "of, by and for" the industry. PRCI's Mission - To be the global leader in collaborative energy pipeline research that provides safe, reliable, environmentally conscious

and efficient means of delivery. The PRCI approach and R&D program is described at the following website. http://prci.org/index.php

Northeast Gas Association - NYSEARCH Committee

The Northeast Gas Association - NYSEARCH Committee (NYSEARCH) has worked for over 30 years as a consortium of natural gas LDC's who have a common interest and need for research and technology development and demonstration. Today, administered as part of the Northeast Gas Association, NYSEARCH manages over 30 projects in various stages of development for LDCs, transmission companies, federal agencies and their manufacturing and commercial partners. NYSEARCH's overall objectives are to: 1) Assess and address technology needs and opportunities as the business and technology environment changes, 2) Produce viable R&D products that provide quantifiable benefits through increased safety, greater efficiency, and reduced cost based on industry priorities, and, 3) Sustain high customer satisfaction through positive financial performance and high funding leverage ratios.

On a product-by-product basis, NYSEARCH also strives to partner with commercial product developers and distributors to aid successful product implementation and to help define market needs and product specifications. More information and details describing NYSEARCH's R&D program is available at the following website. http://www.nysearch.org/

American Gas Foundation

The American Gas Foundation (AGF) is committed to making sure the right questions are being asked and answered. AGF funds independent, critical research that can be used by policy experts, government officials, the media and others to help formulate fact-based energy policies that will serve this country well in the future.

Founded in 1989, the AGF is a 501(c)(3) organization focused on being an independent source of information research and programs on energy and environmental issues that affect public policy, with a particular emphasis on natural gas. Overseen by a board of trustees, the AGF has delivered numerous key public policy reports since 2000 and has sponsored executive level forums and events focusing on energy supply. Information on the research and program activities of the AGF can be found at the following website.
http://www.gasfoundation.org/AboutAGF/Index.htm

Interstate Natural Gas Association of America Foundation

The INGAA Foundation was established in 1990 and includes membership which is open to natural gas pipelines and companies that provide goods and services to pipelines worldwide. Today, the INGAA Foundation has more than 150 member companies representing natural gas pipeline companies, construction companies, engineering firms, pipe and compressor manufacturers, accounting firms, companies providing information technology services and other suppliers of goods and services to the pipeline industry.

The Foundation's primary activity is to sponsor research aimed at promoting natural gas use and safe, efficient pipeline construction and operation. Since 1990, the Foundation has completed over 110 studies, in addition to many projects and workshops which benefit the industry. These projects focus on key industry issues such as environmental impacts of energy

use, improved pipeline construction practices, pipeline safety procedures, new technologies and market opportunities for natural gas.

The Foundation also sponsors briefings and conferences on topics of special interest to its members. These conferences promote information exchange and foster communication among pipelines, contractors, service providers, and representatives from government agencies and academic institutions.

Information on the research activities of the INGAA foundation can be found at the following website. http://www.ingaa.org/Foundation/16435.aspx

U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration

The PHMSA conducts and supports research to support regulatory and enforcement activities and to provide the technical and analytical foundation necessary for planning, evaluating, and implementing the pipeline safety program. PHMSA is sponsoring research and development projects focused on providing near-term solutions that will increase the safety, cleanliness, and reliability of the Nation's pipeline system.

Recent R&D projects are focused on: leak detection; detection of mechanical damage; damage prevention; improved pipeline system controls, monitoring, and operations; and, improvements in pipeline materials. These projects are addressing technological solutions that can quickly be implemented to improve pipeline safety.

The mission of PHMSA's Pipeline Safety Research Program is to sponsor research and development projects focused on providing near-term solutions that will improve the safety, reduce environmental impact, and enhance the reliability of the Nation's pipeline transportation system.

This Research Strategic Plan aims to convey many messages but mainly that we:

- Employ a coordinated and collaborative approach to address mutual pipeline challenges
- Help remove technical and sometimes regulatory barriers on a given challenge
- Measure our research results, outputs and impacts
- Are transparent virtually posting all program processes, actions and products on our program website.

A full listing of PHMSA R&D projects is provided at the following website. http://primis.phmsa.dot.gov/rd/index.htm

The industry and the R&D organizations that serve it are keenly aware of the challenges and needs related to pipeline assessment and monitoring. Key challenge areas that need significant R&D (not in any particular order) include:

- Unpiggable pipelines
- Above ground inspection tools
- Longitudinal seam welds
- Data integration and decision making tools

- Industry database of pipeline incident statistics
- High risk infrastructure
- Valve spacing, automation, remote control valves
- Leak detection
    - Remote, low cost methane detectors in the 100 to 200 ppm range with an alarm
    - Improve time to detection and validation
    - Reduce false alarms, improve alarm management
- Depth of cover, subsidence, and land movement
- Emergency response issues
- Control room issues
- Maximum allowed operating pressure (MAOP) confirmation (grandfather clause)
- Alternatives for hydro-testing
- Quality Management System from manufacturing to operations
- Effect of climate change on pipelines
- Improvements in ILI capabilities
- Need to compare ILI to actual failures
- Fitness-for-service
- Risk assessment
- Interactive threats
- Anomaly assessment
- Mechanical damage
- Damage prevention
- Graphitic corrosion on pipe
- Permanent markings of components (fittings)

4.2 Emerging Technology Development - Strategy Elements

The emerging technologies, techniques, methods and tools recommended for consideration by the Energy Commission were a subset of those which were identified through a review of the ongoing technology development efforts to address the high priorities among the challenges listed above. Each of the recommended technologies could be implemented within four years. The recommendations were organized using a technology development strategy built on four strategic elements.

1. Asset Life Cycle Management – "What's Where" –technologies providing an efficient set of capabilities to know what you have and where it is located.

2. System Communications and Control includes emerging technologies to create or enhance the capabilities to communicate and control the system.

3. System Monitoring and Assessment illustrates the technologies needed to assess and monitor the system.

4. Overarching Issues captures a variety of needs and recommended activities that span the entire integrity management process.

The four strategic elements are described in more detail below followed by the selected emerging technologies associated with each element that were recommended for consideration by the Energy Commission. In addition to the description an Emerging Technology Development Roadmap was provided in Appendix D which summarizes the 47 projects or collaborative R&D programs recommended for consideration by the Energy Commission under the respective program areas that are associated with each strategic element. The roadmap showed each project on a development timeline, indicates the projects status (New, Proposed or Ongoing), the organization that is or will be controlling the work effort and the recommended priority (High, Medium or Low).

Asset Life Cycle Management – "What's Where"

Due to the simple fact that natural gas is delivered via a buried infrastructure, knowing the location and characteristics of the delivery system has been, and continues to be, at the core of safe and reliable operations. Natural gas infrastructure has been installed using a variety of techniques, materials, specifications and procedures since the introduction of manufactured gas in the 1800s. As times changed so did the methodologies, attention to detail and record keeping. Existing and future requirements obligate operators to have and maintain complete and accurate data that will be important for integrity management compliance, risk analysis and future system use considerations. The emerging technologies and techniques recommended below were focused on improving the asset life cycle management of the pipeline systems in California. Once deployed these technologies and techniques would be used for all future work with the understanding that there needs to be the flexibility of adding or allowing new or improved features as they are developed.

4.2.1.1 Data Standards and Guidelines

National Utility As-Built Standard

The American Society of Civil Engineers (ASCE) Codes & Standards Board Committee is advocating for the creation of a U.S. standard comparable to the standard that resulted from the efforts of the Canadian Standards Association (CSA) known as CSA S250. The CSA recently addressed the fact that there was no existing standard for underground plant which included the lack of a standard definition of what an "as built" was to provide or who was responsible for omissions or errors. The lack of a set of standards for recording the underground plant has resulted in a high degree of variability in the accuracy, consistency and reliability of information. Recent technology advances have provided the means to improve record capture and storage enhance records access and sharing, reduce the cost of the design cycle as well as the cost to locate, improve safety and improve communications among the operators of the various infrastructures. In the past the equipment to spatially locate the facilities was too costly and personnel were not trained to use it. With today's GPS and hand-held field devices these challenges no longer exist. A set of standards of this type establishes the requirements to ensure traceability, accuracy, precision and reliability of the records.

Status – This would be a new effort to build on the efforts of the CSA, review the CSA S250 standard and support the development and adoption of a similar standard in the U.S.

American Society for Testing and Materials (ASTM) F2897-11[1]

This OTD led development has provided the industry with ASTM F2897-11 as a standardized method to record material and manufacturing properties for the distribution system. This specification defines requirements for the data used in the tracking and traceability base-62 encoding system. It provides the format of the resultant code to characterize various components used in fuel gas piping systems. In this specification, the final output is a 16 digit alpha-numeric code that defines a standardized approach or methodology for encoding certain characteristics of components that have been established based on consensus recommendations from the respective stakeholder group members. On-line systems are being developed to assign component identification numbers, enhanced marking techniques are being developed along with a comprehensive data dictionary of data collection requirements and a publically available database for operators.

Status – To-date, no similar set of standards exists for the transmission system. OTD is conducting the proof of concept testing under the Asset Lifecycle Management – Intelligent Utility Installation (IUI) Phase 2 project initiated in 2012 to determine the requirements to meet the ASTM standard. The proof of concept includes marking durability and permanency testing, the development of asset tracking guidelines and the development of a GIS bar code decoding tool (discussed below). It is recommended that the Energy Commission monitor the development of the OTD project while assessing the effort required, and if feasible participate in the collaborative effort to create, a similar set of standards for pipeline transmission systems.

Asset Tracking Guidelines

A set of guidelines for operators and manufacturers is recommended to support the implementation of the material and manufacturing marking standards described in ASTM F2897-11. The recommended guidelines would address the issues related to the permanency and durability of the bar code markings, how frequently the markings should be made, how the various fittings and appurtenances should be marked and what type of marking techniques should be used.

Status - The development of the guidelines is included in the OTD Asset Lifecycle Management – Intelligent Utility Installation (IUI) Phase 2 project initiated in 2012. It is recommended that the Energy Commission participate in efforts to create the asset tracking guidelines.

4.2.1.2 Tracking and Traceability

Lifecycle Tracking of Specifications and Procedures

The documentation and memorializing of the specifications and procedures used during a field installation was recognized as a need and a potential technology gap that could result in a burden on the back office. It may be possible to use a bar coding technique to document the specifications and procedures within the GIS simplifying the integration of date/time stamped

[1] ASTM, A. S. (2012). Standard Specification for Tracking and Traceability Encoding System of Natural Gas Distribution Components (Pipe, Tubing, Fittings, Valves, and Appurtenances). In ASTM, ASTM Book of Standards Volume 08.04.

design specifications and procedures into the database. This captured data can be used to verify as-built drawings compared to design, the qualifications of the installer and other installation requirements.

Status - It is recommended that this technique and others be evaluated either through an Energy Commission coordinated approach, a company specific approach or through participation in the OTD Asset Lifecycle Management – IUI Phase 2 project initiated in 2012.

Long-Term Traceability

Upon completion of an installation, all necessary data must be retained and be available for future risk assessments and other purposes. Marker balls are microprocessor-based systems that use RFID tags to locate facilities and collect and store field data for later processing to quickly and efficiently locate underground facilities years after construction or maintenance. Information such as a pre-programmed unique identification number, facility data, owner information, application type, placement date and other details can all be stored with date/time stamp and retrieved at a future date for enhanced resource management.

Status – This technology is commercially available but use varies. It is recommended that the Energy Commission advocate the use of this technique and other similar proven technologies as part of field installations.

4.2.1.3 Records Management

Geographic Information System (GIS)

A GIS is recommended as the data repository for all existing and future field installations. A GIS is capable of receiving field data on a real-time basis and being integrated with other enterprise systems. This approach would result in spatially defining the point of information once and populating each of the enterprise systems with up-to-date field data. Enterprise system would include but not be limited to work order management, asset management and customer management systems and software packages used for operations such as SCADA, and hydraulic simulation applications (such as Stoner). In addition, a GIS can be used to perform trend analysis and threat identification as well as being capable of providing operators a means of visualizing system performance under normal as well as compromised scenarios allowing "what if" contingency analysis. It is important that the GIS be capable of maintaining history so that not only the current condition of the system is visible but also what the system looked like at any given time in the past.

Status – Based on the interviews conducted during Task 2, the use of a GIS varied by operator from the simple use for creating maps to more sophisticated data utilization. The majority noted the need for improvements or upgrades to existing systems along with the need for an integrated solution that would allow the single entry of information resulting in immediate availability across the enterprise systems. The Energy Commission should support upgrading of the GIS at each operator, and the integration of the GIS with each enterprise system and software package used for operation. An approach of this type would be complementary to the strategy for optimizing and leveraging the AMI in California.

4.2.1.4 Database Integration

GIS Barcode Decoding Tool

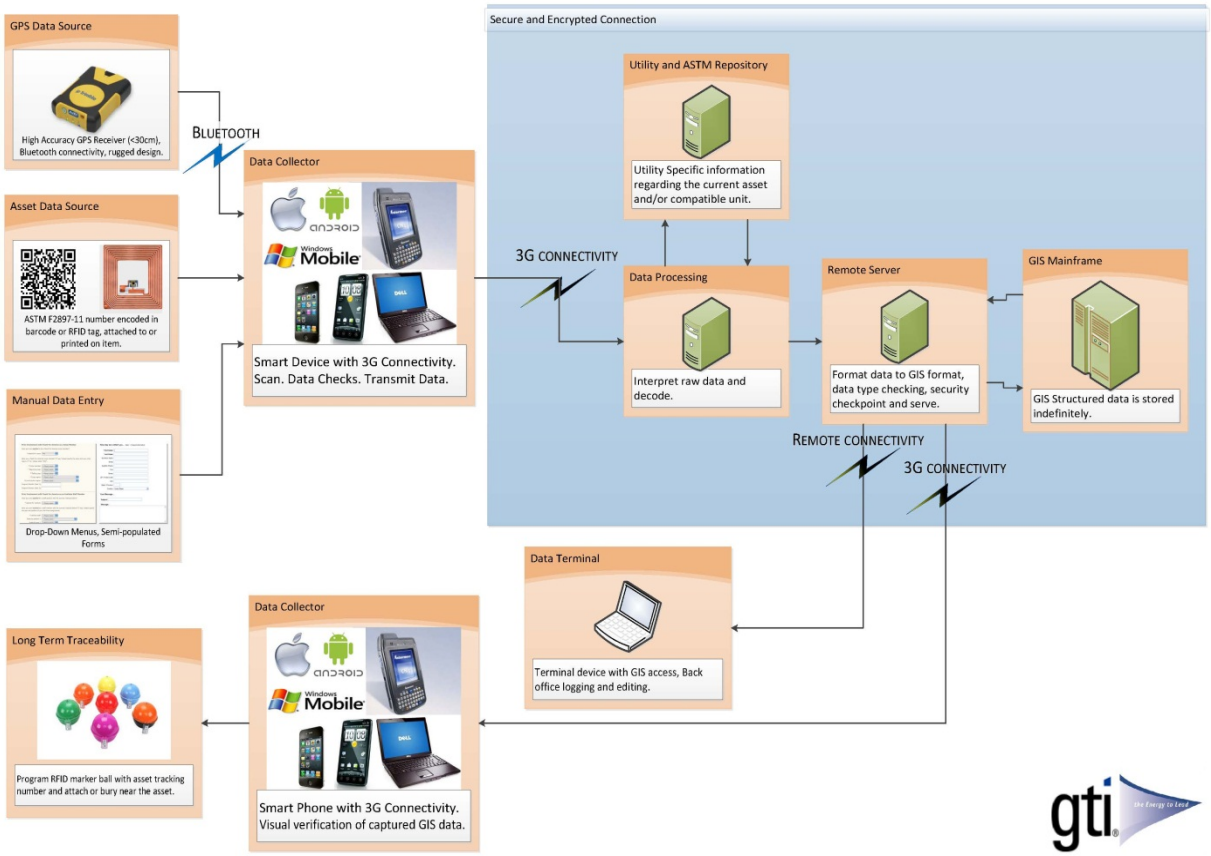
The use of a bar code or other methodology to capture the data in the field provides a quick and accurate method to automate data collection; however, that number by itself requires interpretation or decoding to be useful to the operator.

Status - The development of an application that can be used to decode the tracking number and insert the actual features of the data collected into a GIS is part of the development effort in the OTD Asset Lifecycle Management – IUI Phase 2 project initiated in 2012. It is recommended that the Energy Commission participate in efforts to create the GIS barcode decoding tool.

4.2.1.5 Field Data Capture

Technologies to efficiently capture field data that reduce or eliminate human error while improving the real-time availability of the data have been identified as a longstanding need of the industry. Emerging technologies such as those discussed below coupled with communications improvements and the use of GIS as a data repository, each discussed elsewhere in this report provide a key pathway to the leveraging and optimization of the AMI in California. Figure 1 illustrates how the concept comes together.

Figure 1: Process Flow of Bar Coding Technology with Hand-Held Devices Integrated with GIS



Source: GTI

Hand-Held Field Data Collection Device

A variety of hand-held devices are available ranging from phones to tablets to laptops for field data collection. The key to success is having a device that is light weight with a battery life sufficient to function for a full work day, a high precision integrated GPS and a data entry process that is intuitive and limits creative entry. No single device exists today with these features fully integrated. GTI has ongoing efforts in this area of technology development and is working with 3-GIS to provide a software system with a data entry process that features drop-down pick lists on a series of screens tailored to emulate the data collection flow of the installation process. The goal is to communicate real time data to and from the field, eliminate paper and provide a single point of entry to the GIS database. Recent developments in GPS technology (discussed below) are providing unprecedented locational accuracy without the requirement of post-processing of the data. The one drawback that remains is the ability to view the screen display in bright sunlight.

Status - This technology is in the field demonstration phase and is anticipated to be available for deployment in 2013. It is recommended that the Energy Commission advocate the use of this technique and other similar proven technologies as part of field installations. The adoption of this technology would be complementary to the strategy for optimizing and leveraging the AMI in California

Mobile Device Area Network

As sensors become more advanced and digitized, the essential gap that will need to be crossed is the ability to accomplish short-hop communications between sensors and hand-held devices while addressing data transfer and security concerns. A mobile device area network would provide a variety of infrastructure options, data-rate bandwidths and interchangeability to best fit the given application. Regardless of the sensor type, data could be transferred over Bluetooth, RFID, Zigbee, Wifi Networks, and other forms of low power, robust, secure layer-based radio waves. These methods are defined by Institute of Electrical and Electronics Engineers (IEEE) industry standards which ensure cross-platform compatibility with any classified device.

Status – This is a new technology development concept that would be complementary to the strategy for optimizing and leveraging the AMI in California. It is recommended that the Energy Commission create and/or participate in a project to develop this communications capability.

High Accuracy GPS

The accuracy of a GPS device varies from navigational grade typical of those used for vehicle navigation or recreational use to survey quality. The fact that natural gas is distributed via underground facilities indicates that the highest locational accuracy possible at a reasonable cost is preferred. Until recently post processing of the data was required to attain a high accuracy GPS location. GTI and 3-GIS have been working with NavCom to develop a GPS capable of real-time, near survey quality locational accuracy that does not require post processing.

Status - This technology is in the field demonstration phase and is anticipated to be available for deployment in 2013. It is recommended that the Energy Commission advocate the use of this technique and other similar proven technologies as part of field installations.

Bar Coding for Asset Tracking

Bar coding technology that complies with ASTM F2897-11 and is integrated with high accuracy GPS and a hand-held field data collection device provides a combination of technologies significantly improving asset tracking and traceability and field data collection efficiency while reducing data entry requirements and eliminating human errors.

Status - A simplified version of a bar coding system was among the technologies demonstrated by GTI staff performing the technology development for OTD in May, 2012. Significant work is still required to fully test and implement the material and manufacturing marking standards described in ASTM F2897-11, this work is described in the OTD Asset Lifecycle Management – IUI Phase 2 project initiated in 2012. It is recommended that the Energy Commission work with ASTM and others to develop similar capabilities for transmission pipelines and advocate the use of this technique and other similar proven technologies as part of field installations.

RFID Tags for Asset Tracking

RFID tags use a wireless system to transfer data using the electromagnetic field used to query them as their source of power. RFID tags offer an alternative to bar coding as an asset tracking and traceability tool as they do not require being within a line of sight to be read as does a bar code and have the additional feature of being able to be read while being buried. In concept all the advantages of using bar codes for field data capture in compliance with ASTM F2897-11 are possible with RFIG tags. RFID tags, like bar coding, face a similar set of challenges related to material and manufacturing marking standards and longevity.

Status – The evaluation of RFID tags for field data capture is a new concept. It is recommended that the Energy Commission create and/or participate in a project to develop this tracking and traceability capability.

Pipe Rover Platform for Above-Ground Surveys

Pipeline survey data is most often collected by hand and related to a hard geographic coordinate after the fact. The manual collection of the data in the field can have errors from operator inexperience or fatigue. The process of reconciling data from multiple sensors or surveys to map locations after the fact is both labor-intensive and error-prone. This project will develop a standard platform and interface for existing and future sensor technologies. This standard platform will provide a means to rapidly test new above ground pipe-assessment sensor technology without the need to develop these common features each time. A platform that automates the field collection and geo-stamping of the data can eliminate errors and reduce the labor involved in a survey.

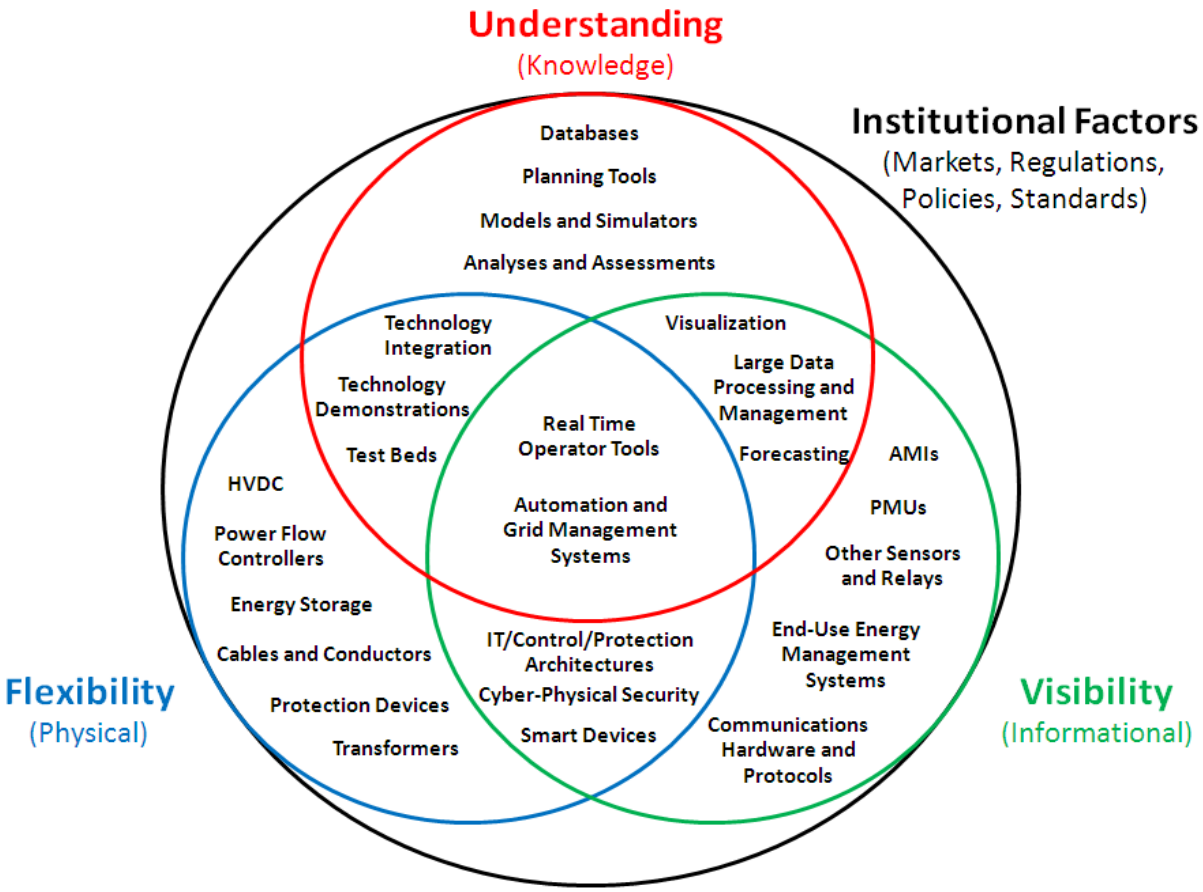
Status – This project has been proposed by GTI to SMP. Assuming the project goes forward the scheduled completion of the testing of the platform with an on-board sensor will be the fourth quarter of 2013. It is recommended that the Energy Commission consider participation in the development and subsequent field trials of this technology.

System Communications and Control

The energy grids (electric and natural gas) serving the United States are undergoing a transition. Allan Schurr – Vice President, Strategy & Development, Global Energy and Utilities, IBM succinctly described this transition at the United States Department of Energy (USDOE's) Electricity Distribution System Workshop, September 24-26, 2012. At present, each grid is operated through the use of instrumentation at key points resulting in the independently operating energy grids that have successfully served millions of consumers. The first layer of transition is the overlaying of each of these instrumented energy grids with a series of interconnected monitors, sensors and control devices that are providing an improved level of capability. This improved level of capability is primarily reactive in nature, providing alarms if a limit is exceeded or an event occurs and may also include a level of automation to respond to the event or a signal that the event warrants the attention of an operator. The energy grids of the future would move this capability to a higher level. The energy grids would be interconnected and have optimized their interdependency. Computing capability would be capable of handling the volume, variety and velocity of the data to provide an intelligent energy delivery system with insight and predictive capabilities.

The Workshop noted above was coordinated by the USDOE Grid Tech Team (GTT) to engage a broad group of stakeholders. The draft vision used to initiate the Workshop included three focus areas for R&D activities that would result in a modernized grid able to "see" an event, "know" what is happening, and "do" something appropriate in response – quickly and seamlessly. It was also noted that there was overlap and interactivity among these three technical focus areas as well as many institutional factors (markets, regulations, policies, standards, etc.) that underpin and influence the success of R&D activities. The draft vision was: "A seamless, cost-effective electricity system—from generation to end-use—capable of meeting all clean energy demands and capacity requirements, while allowing consumer participation and electricity use as desired." Figure 2 is used to represent this vision as shown below:

Figure 2: Strategic Framework for Grid Modernization



Source: USDOE GTT

The initial focus of the workshop was on the electricity system; however, during the course of the Workshop it became increasing apparent that the electricity system was essentially a system within the larger energy system and that natural gas was another key component of that energy system. In large part the simple substitution of the word energy for electricity in the figure above captures that larger vision. Other than the substitution of infrastructure specific items in the Flexibility (physical) area, many of the needs and gaps noted as part of the three focus areas shown in the figure above (Flexibility, Visibility and Knowledge) are common for the future interdependent energy system and are recognized among the emerging technologies recommended in this report.

The natural gas industry recognized the need to integrate the natural gas infrastructure with an increasingly smart electricity grid and developed a white paper[2] in 2011 that presented a compelling vision of how a smart energy future in which natural gas is effectively integrated has the potential to deliver several important advantages:

[2] Natural Gas in a Smart energy Future, GTI and Navigant Consulting Inc. 2011. http://media.godashboard.com//gti/Natural_Gas_in_a_Smart_Energy_Future_01-26-2011.pdf

- Improved safety, energy security, and environmental performance;
- A more efficient infrastructure, with the ability to provide demand response, accommodate emerging technologies, and new sources of supply;
- Improved demand response for electric distribution through switching heating and cooling loads to natural gas and through the use of distributed generation;
- Greater consumer choice resulting in maximum energy value; and
- More optimized energy value from renewable wind and solar through the use of fast ramping dispatchable generation.

Failing to realize a smart energy future in which natural gas is not effectively integrated could create or exacerbate a number of problems:

- The delivery infrastructure will not be at an optimal level for society;
- Higher energy costs for consumers;
- Consumer options for efficient energy use will be limited;
- Greenhouse gas emissions will increase and be more costly to manage;
- The increased use of intermittent renewable energy sources will create performance issues for the electric grid that could have been effectively addressed; and
- Demand response options for the electric distribution system will be limited and more costly.

4.2.2.1 Communications

Communications is at the heart of attaining the vision of a smart energy future. An approach that includes redundant real-time two-way communications, the deployment of monitoring and control devices that are interoperable and leverages and optimizes the capabilities of the AMI systems in California provides the basis for an integrated energy delivery system.

Communications is a rapidly evolving area of technology development and deployment, much of which is conducted by the private sector with numerous startup companies actively striving for a segment of the market place. No single path is ideal for all situations nor is it possible to describe every technique or approach due to the proprietary nature of this area of technology development. It is recommended that the Energy Commission focus their efforts at the system level ensuring that every technology to be deployed has been independently certified as interoperable and that the capabilities of the AMI are verified as described below.

4.2.2.2 Interoperability

Interoperability Standards

The National Institute of Standards and Technology (NIST) initiated the Smart Grid Interoperability Panel (SGIP) to support NIST in fulfilling its responsibility, under the Energy Independence and Security Act of 2007, to coordinate standards development for the Smart

Grid. Established in late 2009, the SGIP is a public/private partnership that defines requirements for essential communication protocols and other common specifications and coordinates development of these standards by collaborating organizations.

The SGIP is comprised of over 780 member organizations representing 22 stakeholder categories, including federal agencies as well as state and local regulators. More than 1,900 individuals are participating in SGIP activities. Membership is free and open to all organizations interested in achieving the Smart Grid vision.

GTI on behalf of OTD initiated a project in 2011 to ensure that the infrastructure requirements that are specific to the natural gas industry are included in the ongoing technology, standards, and regulatory initiatives currently focused on the electric smart grid initiative. Due to the ongoing nature of these efforts that are currently electric-centric, it is important that the gas industry becomes fully engaged in the ongoing dialogue.

Under the guidance of the SGIP the Gas Technology Domain Expert Working Group (GT DEWG) held its first meeting in August 2012. To effectively leverage and optimize the use of the AMI for natural gas pipeline operations a common communications protocol is essential. Support of and involvement in the GT DEWG by a wide variety of stakeholders including state and local regulators will help ensure that the AMI in California and elsewhere is fully interoperable.

Status – This newly formed investigative effort is being coordinated by GTI for OTD and is seeking additional stakeholder participants. It is recommended that the Energy Commission become an active member of this group and/or support one or more participants.

4.2.2.3 Control - Leveraging and Optimizing of the AMI

The AMI system in California is not a single system it is composed of a combination of public and private communications systems that include a variety of methods of communication such as phone, cable, cellular, radio and satellite. The long-standing debate over a public versus a private network continues. There are trade-offs between cost, availability and reliability given the wide variation in population density, distances covered with pipeline facilities and geography. One of the major criticisms of being dependent on the public networks is reliability and availability during an event. The following projects are recommended to attain an optimized use of the AMI.

AMI Capability Verification

For the pipeline operators to depend on and optimize the use of the AMI for pipeline infrastructure monitoring an independent verification of the capabilities is recommended. The verification should include but not be limited to:

- System security – cyber as well as physical
- Redundant two-way communications – assurance of a viable two-way communications path under the full range of potential circumstances
- Access – full access that includes availability as well as interoperability

Once verified, a wide variety of beneficial uses are possible including:

- Low cost, low power communications network using technologies:
  - Placed at smaller intervals resulting in an accurate "picture" in real-time including methane detection, system flow and pressure monitoring
  - For remote applications to expand the SCADA system
- Data collection, monitoring and system control as new technologies are developed – Ex. ROW encroachment and excavation damage prevention, leak detection
- Improved operation of selected valves
- Instantaneous identification of an issue or failure requiring pipeline shutdown

Status – This would be a new effort. It is recommended that the verification and quantification of the capability of the AMI system be the first priority of the Energy Commission. The outcome of this verification and quantification effort will result in a series of projects to attain a viable system for use by the transmission operators in California.

4.2.2.4 Control - System

Transmission EZ Valve

This is a proof of concept project to assess the capability of installing a permanent cut-in valve on a live transmission gas line. The current EZ valve system is used in the water industry and operates at pressures up to 100 psig. A concept to develop a valve similar to the EZ valve used in the water industry but designed for the higher pressures found in the gas industry was developed in response to the challenges identified with installing automatic shut-off valves and remote control valves at the PHMSA R&D Forum held this past July, 2012. The work will include the consideration of all material issues, geometric constraints and operational needs.

Status – This project has been proposed by GTI to be initiated by SMP during the fall of 2012, the planned completion date is the second quarter of 2014. It is recommended that the Energy Commission participate in this SMP project to develop the capability of installing a permanent cut-in valve on a live transmission pipeline.

System Monitoring and Assessment

The re-occurring theme from the interviews, brainstorming sessions and workshops was the need for low cost sensors providing real-time data to enhance the safe and reliable operation of the pipeline system. Many of the sensor types requested exist today, the challenge is to make them low cost and low power. The benefit of being low cost, low power and capable of being connected to a two-way communications network provides the operators with the opportunity to use the sensors on a more widespread basis increasing the chance of early detection of a change or an item of concern.

4.2.3.1 MEMS – UC Berkeley

MEMS Sensor Development

The University of California at Berkeley (UC Berkeley) is conducting a concurrent effort funded by the Energy Commission focused on Micro Electro-Mechanical Systems (MEMS) technologies for the gas industry. The details of the investigative efforts of UC Berkeley on MEMS sensor development are provided in their reports. The variety of sensors of interest to the pipeline operators in California are shown below with the first four being listed in priority order:

- ROW encroachment and excavation damage
- Pressure
- Flow - measure to +/-5% could be sacrificial if the pig goes by
- Vibration - would provide value as they have issues with the locations being damaged by large trucks driving into the facilities – need to be able to differentiate from normal operations
- Gas quality sensors – "Gas Chromatograph (GC) on a chip"
- Moisture
- Odorant
- Methane

Status – The sensor technology evaluation and development efforts at UC Berkeley are underway. It is recommended that the Energy Commission continue to support the efforts of UC Berkeley while expanding this program area to include field testing, demonstration and deployment that will meet the requirements of the operators, regulators and manufacturers.

4.2.3.2 Monitoring Devices for ROW Encroachment and Excavation Damage Prevention

The issue of encroachment and excavation damage on ROW's was included in the Task 3 report, which summarized currently available technologies. Due to the fact that this type of event has been and continues to be widely recognized as the single highest reason for pipeline leaks and accidents the summary of that concern is worth repeating. Excavation damage has accounted for over 23 percent of the transmission and 38 percent of distribution pipeline incidents since 1992 as summarized by PHMSA. Knowing when someone is on the ROW has immediate value to the pipeline operator, having a cost effective method(s) to differentiate that knowledge of the presence of someone to a determination that a potential threat exists, and action may be required has significant value to maintaining a safe and reliable energy delivery system.

Knowledge of ROW encroachment and excavation damage prevention can be obtained using either visual or vibration monitoring technologies. Methods capable of being cost effectively deployed (a first order, high level estimate places this value at less than or equal to $100,000/mile) for retrofit on existing pipeline installations were viewed by the industry as being of greatest value. Techniques for either retrofit or new installations that are recommended for consideration by the Energy Commission are described below.

GPS Based Excavation Encroachment Notification (EEN) for ROW Monitoring

A two part EEN development effort was conducted in Virginia starting in 2005 to use GPS technology as part of the creation of one-call tickets. This was expanded to include a third effort in 2008 which included two phases. The first phase was to use GPS technology to monitor excavation activity to alert the operator when excavation activity occurred outside the one-call delineated area. The second phase was to develop a more precise monitoring system that would alert the operator when they were digging too close to underground utilities. The project successfully demonstrated the technology, but the technology was considered complicated and costly.

Status – The EEN technology investigative efforts are being provided by GTI for OTD, the project is in the field scale demonstration phase. The ongoing work in New York builds on the work to-date with a validation of improved EEN technology including equipment compatibility testing, evaluation of lower cost/less complex monitoring systems and a larger scale work area. Additional EEN technology evaluation testing would accelerate the deployment of this technology. Projected completion of the phase ongoing in New York is scheduled for the fourth quarter 2013. It is recommended that the Energy Commission consider supporting the California pipeline operators in working with GTI to translate the EEN concept from the current focus on distribution to a focus on transmission ROW monitoring followed by a demonstration project in California.

Sensor Development for ROW Damage Detection and Operational Improvement

Pipeline operators need to know the conditions along their pipeline ROW. Several technologies have been proposed to address this issue; many of these require fiber optics or other continuous sensors to be installed in the right of way. While continuous sensors may be appropriate for new construction, they are not practical for the larger population of existing pipelines. This multi-phase project would develop and verify the capabilities of a retrofit ROW monitoring system for existing distribution or transmission pipelines. This technology is envisioned to consist of the following components: 1) An off-grid power supply; 2) A wireless communication system; 3) A suite of sensors to monitor the pipeline and 4) Software to identify events of interest from the sensor data. This system would be designed to provide real time intelligence on incursions into pipeline ROW's enhancing public safety by reducing the risk of third party damage. The suite of sensors used for this monitoring would also provide operational data without the need for personnel visits. This operational data could include: 1) Cathodic Protection potentials; 2) Gas Pressure and 3) Valve Status.

Status – CIEE/UC Berkeley and GTI are collaborating on a proposal to PHMSA to develop a system capable of being field tested in 3 years. It is recommended that the Energy Commission participate in this project to develop this capability for ROW monitoring.

Advanced Learning Algorithms for the Proactive Infrasonic Pipeline Evaluation Network (PIGPEN) Pipeline Encroachment Warning System

Physical Sciences Inc. (PSI), with American Innovations Ltd. (AI) and NYSEARCH, are addressing the technology gap of Early Warning Damage Prevention Monitoring Systems, specifically Advanced Development of Algorithms for Detecting Digging Threats and Avoiding

Alarms. This research will implement and evaluate self-training algorithms in the Proactive Infrasonic Gas Pipeline Evaluation Network (PIGPEN) autonomous distributed seismic sensor system. PIGPEN provides real-time warning of unauthorized right-of-way encroachment and excavation activity near a pipeline. Early warning enables a response to the potential intrusion in time to prevent pipeline damage, and thus preclude the additional cost and risk of repairs. The ideal PIGPEN alarm system would activate an intruder notification with 100% reliability and no alarms. The project will enhance reliability by enabling PIGPEN to learn the characteristics of its local environment and optimize its intruder detection algorithms based on learned experience. Field tests are expected to demonstrate better than 97% alarm reliability with few alarms.

Status – This research is ongoing and being administered by PHMSA with the technology gap being addressed by PSI, with AI and NYSEARCH. The proposed completion date is the fourth quarter of 2013. It is recommended that the Energy Commission participate in this PHMSA project to develop an early warning damage prevention system.

4.2.3.3 Monitoring Devices for Leak Detection

The natural gas industry is constantly seeking new or enhanced leak detection techniques to improve the safety and reliability of the infrastructure. The majority of techniques in use today use a survey approach where the system is assessed on a periodic basis resulting in an instantaneous view or "snapshot" of the leak status of the system.

As the communications infrastructure and sensing technologies capable of providing actionable data on a real-time basis improve, new approaches are gaining favor to improve safety for consumers and utility workers. Leak detection technologies recommended for consideration by the Energy Commission are described below.

Mobile Leak Detection

Advances in mobile equipment and laser spectroscopy have made fly-by leak detection of pipelines possible, using infrared signature identification and LIDAR to scan a large area below the flight path and pinpoint natural gas plumes from hundreds of feet away.

This method is faster and safer than conventional walked/driven surveys and may minimize the probability of missing a leak indicator. Photographs are taken of area being scanned to better identify leak location. The device allows for pipelines in harsh, overgrown, or impassible environments to be scanned for leaks without endangering utility personnel.

While a scanning sensor may be useful for long-range scans and leak detection, some might find the accuracy and precision to be lacking. The Picarro G1301 is a real-time (updates 10 times a second) ambient gas analyzer that can monitor precise (up to ppbv) amounts of CO_2/CH_4 and (up to ppmv) H_20. These measurements are taken locally, sampling the ambient air, and analyzed for any carbon-based gases. This means that the mobile craft must fly/drive/navigate through the areas of concern, possibly putting the operator at risk. But if the LDC's goal is to locate a small but potentially hazardous leak, or verify that levels are safe for the local environment, this device has the potential to repeatedly and reliably offer high sensitivity carbon-based gas detection.

Calibration is completed at the factory and requires no adjustments or maintenance for the lifetime of the product. This technology has been integrated into a field-ready unit capable of rapid air quality profiling and chemical detection on high speed vehicles. This technology comes at a high price tag and requires significant preparation for field use or adapting it to the vehicle of choice. A connected PC is required for operation, and thus a substantial power source is also needed. Detectable gas types are defined and calibrated for each unit and not adjustable in the field.

Status – The Picarro technology is being evaluated by Pacific Gas & Electric (PG&E) and others in the industry. It is recommended that the Energy Commission maintain an awareness of the evaluation as a potential leak detection technology for use in California.

Smart Pipeline Network - Pipe & Repair Sensor System

This PHMSA Small Business Innovation Research (SBIR) project focuses on the development of a Pipe and Repair Sensor System. When combined with the Seal Sensor System (being developed separately), this technology will allow for a Smart Pipeline Network having integrated sensor networks that provide for continuous real-time monitoring of leaks and system health.

In this program, smart pipes and smart composite repair having integrated leak detection micro-sensors will be further developed and adapted for pipeline use. Concepts and designs will be developed for a networked sensing system capable of sensing the pinpoint location of a leak or impending leak, as well as monitoring structural health. In Phase I, the scope will include the development of a Pipe and Repair Sensor System for use with petroleum-based liquids, with Phase II expanding the scope to include development of a system for use with natural gas.

Once developed, the oil and natural gas pipe/repair sensor network will be useful for pipeline operators to continuously monitor the health of the pipeline system and to detect leaks. Other commercial applications will include gasoline stations, oil storage facilities, methane plants, oil and gas transportation, and off-shore oil rigs.

Status - This research is just getting underway and being administered by PHMSA with the investigative efforts being addressed by Odyssian Technology LLC. The proposed completion date is the first quarter of 2013. It is recommended that the Energy Commission monitor the development of this capability as it applies to natural gas and consider participation in subsequent phases depending on the results.

Evaluate Acoustic Leak Detection Technology for High Pressure Pipeline

Advances take place in every segment of the energy industry and when a technology shows success in one segment there is the potential to consider the use of that technology in another segment of the industry. A successful transition of technology provides a shortened development cycle, and the ability to obtain a technology with improved capabilities at a lower cost. Asel-Tech, Inc. developed and commercialized an acoustics based leak detection technology in 2008 for use with liquid pipelines. The natural gas pipeline systems have similar needs to identify and be notified of leaks at all operating pressures on a real-time basis. This

new technology evaluation and demonstration is focused on verifying the capability to detect leaks in natural gas transmission pipelines.

Status - The status of this project has been updated since the Task 4 report, this project was proposed by for evaluation in the fall of 2012; however, funding was not secured. There is no action on the evaluation of this technology for use by the natural gas industry at this time. It is recommended that the Energy Commission consider this technology for future funding.

4.2.3.4 Inspection Tools – ILI for Unpiggable (non-piggable) Pipelines

The natural gas transmission system in California is continually being upgraded to allow the use of ILI tools on a universal basis. However, the near term status of the system includes miles of non-piggable pipe that are required to be inspected. There are a number of providers of robotic inspection platforms that have the potential to be viable for use in California. Given the interests of the Energy Commission to deploy integrity management technology in the near future, and the existing development efforts underway by California pipeline operators, the following emerging technologies are recommended for consideration for the inspection of unpiggable pipelines. The development and deployment of the Explorer series of robotic platforms should be the focus of the efforts supported by the Energy Commission where inspection tools with untethered capabilities are of interest. The Pipecrawlers intervention tool should be evaluated where tethered applications are of interest.

One of the more promising sensor technology development efforts is the transfer of the use of EMAT sensors from piggable to unpiggable pipe, described in more detail below.

Explorer Series of Robotic Inspection Platforms

One of the more challenging areas for inspection technologies is that of non-piggable pipe and cased pipes. This area of technology development, supported by PHMSA since 2004, has been one of the major focus areas of the integrity management R&D Program at NYSEARCH since 2001. The NYSEARCH program has developed and continues to upgrade and improve techniques and tools capable of inspecting the non-piggable piping systems and cased pipes owned and operated by LDC's that include pipelines operating at transmission pressures and flow rates. The Explorer series of inspection platforms consist of a remote controlled, battery operated untethered robotic system inserted into the pipe under live conditions through a launch assembly. Explorer has multiple sensors capable of inspecting piping with diameters from 6 to 36 inches. The inspection system includes lighting, fisheye cameras, remote field eddy current (RFEC) and MFL sensors to measure wall thickness, and wireless transmitters and receivers to communicate with sensors for data transfer and location of the robot.

Status – The Explorer platforms and sensors (RFEC and MFL respectively) are commercially available through Invodane Engineering for pipe with diameters of 6″ – 8″ and 10″ – 14″. [For more information, visit www.pipetelone.com .] Also, by the end of 2012, the Explorer 20/26 will be commercially available (for diameters from 20″ – 26″). The other sizes and additional sensors to measure mechanical damage, ovality and cracks are considered to be emerging and are expected to be available on the various sized platforms in 2013 and 2014.

Figure 3: Photographs of the Explorer Robot

Source: NYSEARCH

Pipecrawlers

Pipecrawlers provides a tethered brush drive and suspension system with a modular tool layout capable of transporting a combination of existing inspection technologies such as MFL and UT sensors as specified by the client under live operating conditions. The brush drive and suspension system provides bi-directional movement including the ability to stop and secure itself in positions anywhere in the pipeline, including risers. The integration of both established and new pipeline inspection and intervention into the range of crawlers available will be carried out by Pipecrawlers in partnership with the client and the technology provider.

Status – Current sensors include MFL and UT with crawlers for diameters of 10 and 12 inch. Additional sensor capability is planned with larger and smaller diameters including 6 inch being developed for deployment in 2013 and 2014.

Figure 4: Photographs of the Pipecrawlers

Source: Pipecrawlers

EMAT for Unpiggable Pipe

EMAT has been available from several vendors for decades as a technology with the capability to detect and characterize corrosion, cracks, mechanical damage, coating disbondment and other defects without the need for a liquid couplant. To-date the application of the technology has been limited to large diameter piggable pipelines with launchers and receivers. As noted above, advances are taking place for the platforms used to investigate unpiggable pipelines; this development effort is designed to transfer the EMAT sensing technology as well. PRCI and GTI have projects related to the evaluation and improvement of EMAT technology.

Status – GTI has a new project initiated by OTD in the fall of 2012 with the projected completion of a bench scale system by the end of the second quarter of 2014. It is recommended that the Energy Commission participate in this OTD project to develop EMAT sensing technology for use in unpiggable pipelines.

Dry Hydro – Phase 2

This project will develop and test a laboratory scale alpha prototype of the dry hydro test method developed under an SMP project. The method was designed to be conducted under "live" conditions (flowing gas) while considering geometric and operational restrictions related to non-piggable pipelines or pipelines not able to be hydro tested (lines that cannot be shut-down because there is no redundant supply path) that would benefit from a standard hydro test.

Status – The investigative efforts of this proposed project will be provided by GTI for SMP. The project is planned to be initiated in the fall of 2012 with a projected completion date of the first quarter of 2014. Assuming a successful outcome, it is recommended that the Energy Commission participate in the follow-on OTD project which will be proposed to design and test a full scale beta prototype.

4.2.3.5 In-Line Inspection (ILI)

ILI is also referred to as intelligent or smart pigging. The technique results in the inspection of the pipe from the interior using one or a combination of ILI tools. ILI tools include a variety of devices and a vehicle, known as an intelligent or smart pig, that use non-destructive testing techniques during the inspection. There are over 30 providers of ILI tools offering a wide variety of testing capabilities. This area of technology development is under constant improvement with a number of activities undertaken by the private sector. The ILI projects shown below are the priority areas recommended for Energy Commission involvement.

Internal Inspection Optimization (IIO)

IIO is a two-phase project. Phase 1 will develop a roadmap for internal inspection tools that would be used to guide the development of ILI technology. Phase 2 will develop an inspection technology strategy tool that will assist operators in selecting the most appropriate inspection technology for a specific pipe segment to address the unique threats based on pipe vintage, known material properties and known construction techniques. The benefits include: 1) The formulation of an inspection technology development strategy working toward an alternative to hydro-testing where appropriate; 2) A communications approach for use with the public based on sound engineering and scientific principles.

Status – Phase 1 is complete, and Phase 2 is currently being executed under the sponsorship of OTD, PRCI and the INGAA Foundation with a projected completion by the end of the third quarter of 2013. The investigative efforts of this project are being provided by GTI for OTD. It is recommended that the Energy Commission participate in the development of this ILI technology.

Laser Ultrasonic Testing (LUT)

LUT is a non-destructive ultrasonic measurement technique used in other industries to detect material properties of contoured objects. The system uses a high power optical laser beam that rapidly heats a thin region at the surface of the material. The thermal stress creates an ultrasonic wave within the body of the material. Any discontinuity (ex. void in a weld) deforms the ultrasonic wave which is detected by a second lower power laser. Possible uses include the measurement of wall thickness to detect possible areas of corrosion, pitting, voids, weld defects, cracks, porosity or other discontinuities that may compromise the quality or strength of the pipeline.

Status – The status of this technology development has changed since the release of the Task 4 report. At the time of the report the UC Berkeley was working with PG&E to place a LUT unit on a tethered crawler with power and communications for testing. Due to difficulties faced with applying the technology to gas pipelines the development of this technology has been discontinued. No participation by the Energy Commission is recommended at this time.

Real-Time Pipe Movement Detection (Internal and Long Range)

Pipelines undergo a variety of stresses and strains which may arise due to internal gas pressure and normal operations or from pipe bending and movement due to soil settlement, thermal expansion, flooding, seismic activity, ROW construction or other superimposed stresses. When a bending moment or displacement occurs the stress may exceed the design safety margin of the system. This proof of concept project is focused on developing a prototype sensor and laser emitter/detector system to allow the calculation of these stresses in a way that operators can use the system to identify threats and assess the risk to the impacted pipeline segment.

Status – This is a proposed SMP project to be initiated during the fall of 2012, the projected completion date is the end of 2013. It is recommended that the Energy Commission participate in this SMP project to develop pipe movement sensing capability.

UT Tool and Sensor Improvement

PRCI currently has ongoing projects to develop smaller UT sensors to that would improve the sizing of detected anomalies. The research is focused on determining optimal wavelengths to improve detection and characterization. Additionally, further research by PRCI to examine acoustic polymers for us on ultrasonic tools is being explored. This would eliminate the need for a liquid couplant to complete the inline ultrasonic inspection.

Radiography by Selective Detection (RSD) X-Ray ILI Tool

Radiography by Selective Detection (RSD) is an X-Ray backscatter imaging technology being developed for ILI applications to provide non-destructive evaluation (NDE) for both metallic and non-metallic pipeline systems. Features and functionality of the system include:

- Provides visual images and information, near real time.
- Ability to identify, image, and characterize corrosion, mechanical flaws (metal loss), and material defect geometries, as well as identify and image defect geometries and flaws in poly pipe (PE, Composites, Fiberglass, etc…).
- Assess integrity of various joining processes.
- Can be deployed as either an in-line inspection device (multiple platforms) or via external platform/crawler along pipeline exterior.
- Perform external pipeline inspections without removing insulation or coating, eliminating the need to disrupt operations of the pipeline or facility. The RSD X-Ray technology has the capability of inspecting both the interior and exterior pipe wall in a single pass.

Status – The RSD X-Ray system is still under development. The feasibility and initial 3D prototype design was completed by GTI and technology partner (Nucsafe, Inc) under the sponsorship of SMP, PRCI, and the Gas Storage Technology Consortium (GSTC). Development continued under OTD for evaluation of the technologies effectiveness on PE systems and research is currently underway for metallic pipeline effectiveness, also sponsored by OTD. Further research to validate and improve post-processing of the image is required prior to developing a field ready prototype.

EMAT

Incorporating EMAT with inline inspection devices allows a highly diverse and capable technology to join the ranks of other more contemporary technologies, while bringing something very critical to the playing field. An EMAT (electromagnetic acoustic transducer) equipped device can take wall-thickness measurements, size stress corrosion cracks, and detect areas of coating disbondments all without the onerous mandates including purging the pipe of product and using a couplant.

ILI tools with EMAT capabilities are available that transverse the pipeline by means of product flow i.e. travels via a pipeline pig. Because not all pipelines are piggable, robotic platforms have been designed to carry the EMAT device with the navigational capabilities to travel tight bends, reductions and valves.

Status – While available from a variety of manufacturers in various markets, EMAT still has room for improvement. The advancements in this area could lead to much cheaper and simpler inspections, while capturing comprehensive, multispectral, cross-sectional scans of pipelines. EMAT has also been proposed as an alternative to hydro-testing to ensure a comparable level of pipeline integrity with a margin of certainty. Further research to improve and validate EMAT's ability to detect stress corrosion cracks, hydrogen induced cracks, fatigue cracks, hook cracks, and a variety of other irregularities and defects are required. PRCI has current ongoing projects to evaluate the performance of EMAT technology vs. other traditional inspection techniques.

4.2.3.6 Inspection Tools for Above Ground Inspection

Coating Disbondment Detector

Coatings of various types are applied to pipe to protect against corrosion. Coating disbondment provides an opportunity for corrosion to take place. To-date no technology exists that can detect coating disbondment without excavation. The early detection of disbondment allows for correction before substantial corrosion occurs, by detecting the disbondment via an above ground survey the number of excavations are minimized reducing traffic issues and hazards to utility crews and the public. Electromagnetic based technology is being investigated as a means of detecting disbondment where a known signal is injected and phase data is examined in conjunction with the magnitude.

Status – Ongoing, the investigative efforts of this project are being provided by GTI for SMP. Preliminary results are promising, several improvements have been identified and more testing is required to validate the technology. It is recommended that the Energy Commission monitor the efforts of the SMP on the development of this technology. If successful, participate in the development of the prototype.

4.2.3.7 Direct Assessment

PHMSA defines direct assessment[3] as a process of managing the effects of external corrosion, internal corrosion, or stress corrosion cracking on pipelines made primarily of steel or iron. The process involves data collection, indirect inspection, direct examination, and evaluation. Operators use direct assessment not only to find existing corrosion defects but also to prevent future corrosion problems. The following description provides a summary of an emerging direct assessment technology recommended for consideration by the Energy Commission.

Validation of 3D Scanners for Anomaly Assessment

Operators are required to further assess anomalies found during direct assessment of ILI inspections to determine the need for repair. The accuracy, repeatability and reliability of pit gauge measurements are dependent on the skill and experience of the user and may be difficult to obtain if the anomaly is on the side or bottom of the pipe. This project is focused on the validation of one or more laser or structured light 3D scanning tool(s) that, if successful, would eliminate the manual data collection of in-the-ditch anomaly measurements, improve data quality and increase operational efficiency.

Status – This is a proposed project to be initiated by OTD in the fall of 2012 with the projected completion by the end of the third quarter of 2013. It is recommended that the Energy Commission participate in this OTD project to develop anomaly assessment capability.

[3] https://www.federalregister.gov/articles/2005/10/25/05-21233/pipeline-safety-standards-for-direct-assessment-of-gas-and-hazardous-liquid-pipelines

Data Utilization

Any assessment is only as good as the data used in the assessment. A number of recommendations were reviewed under the Asset Lifecycle Management – "What's Where" section. In addition to those items, the following are high level recommendations for consideration as items that the Energy Commission should advocate for as data requirements to improve the overall value and usefulness of every assessment.

- Consistent data collection across the industry based on standards
- A common/consolidated industry database that uses a standard format
    - First step toward the development of a predictive performance based (proactive) modeling tool
- Common terminology for threats
- The recognition of the need to record all the incident related data to allow an assessment of multiple threat interactions
- Resource for training regulators and pipeline operators to ensure consistency in data collection
- Software tools to analyze and mine the data

4.2.3.8 Data Utilization Methods for Stress Assessment

A Quantitative Non-destructive Residual Stress Assessment Tool for Pipelines

Mechanical damage, including dents, bends, wrinkles, and other forms, is the leading cause of all pipeline failures. The mechanically damaged regions act as fatigue crack initiation sites under cyclic loading (present for in-service pipelines). Crack initiation is the first stage of the appearance of fatigue cracking, which becomes much easier to initiate in the presence of damage because of the locally enhanced strain/stress field around the flaw. The damage and residual stresses lower the overall fatigue strength of the steel and its welds. The size and shape of the flaw is known to determine the level of stress necessary for crack initiation and propagation. Determining and detecting the limits of critical damage severity is essential to mitigating crack initiation and, therefore, mitigating fast crack propagation before failure.

Project objectives include developing a system to quantify stress on all common grades of pipeline steel, which can have yield strengths from 40 Kips/Square Inch (ksi) to 120 ksi. The proposed system would be calibrated to:

- Quantify the residual stress measurements;
- Be useful for all other variables associated with steel pipelines to increase accuracy of eStressTM system;
- Detect lift-off variations due to coatings, corrosion product, user handling of sensors, etc.

Additional deliverables will include:

- A determination of optimum data form for integrity management program;
- Training procedures and manuals; The Development of new codes and standards for acceptable residual stress levels for mechanical damage; and
- The deployment of the system in the field.

Status - This research is being conducted by Generation 2 Materials Technology LLC and being administered by PHMSA. The proposed completion date is the second quarter of 2014. It is recommended that the Energy Commission monitor this PHMSA project for potential application in California.

4.2.3.9 Mechanical Damage

In Addition to the mechanical damage assessment capability described above for residual stress assessment, one of PRCI's largest research programs is set up to address in the impacts of mechanical damage via a variety of techniques. They have projects that address the technologies used to detect and discriminate mechanical damage, rank and screen mechanical damage defects, analyze the structural significance of mechanical damage, and create guidelines for inspection and repair of mechanical damage defects. It is recommended that the Energy Commission monitor PRCI's projects in this area for potential application in California.

4.2.3.10 Corrosion

PRCI currently has a corrosion program which has several projects that look at a variety of corrosion related issues. The corrosion program is broken down into three categories of research; internal corrosion, external corrosion, and stress corrosion cracking.

Key focus areas for the internal corrosion program include the validation of NDE technologies for inspection from the pipe exterior, validation of internal corrosion direct assessment techniques, as well as microbial induced corrosion detection.

The external corrosion projects are focused on: analyzing and modeling corrosion growth rates, inline inspection measurement and uncertainty management, coatings, cathodic protection, improvement to assessment methods, external corrosion direct assessment (ECDA), and preventative and mitigative strategies for microbial induced corrosion.

PRCI's stress corrosion cracking research is focused on the development of guidelines and improvements to technology for the detection and characterization of SCC. Current projects are related to the development of models to assess pipeline data in order to predict failure, as well as development of guidelines to provide operators safe grinding limits for elimination.

Status - PRCI's corrosion program is ongoing and contains many projects. It is recommended that the Energy Commission monitor this program for funding opportunities.

4.2.3.11 Data Utilization Methods for Risk Assessment

Incorporating Interactive Threats in Kiefner/NYGAS and other Risk Models

The objective of this project is to identify and quantify effects of interactive threats and to incorporate that methodology into the Kiefner risk assessment model as well as stand-alone software (for users to incorporate into other risk models where appropriate). The nine top threats listed in American Society of Mechanical Engineers (ASME) code are: external corrosion, internal corrosion, stress corrosion cracking, manufacturing related defects, welding/fabrication related defects, equipment, third party/mechanical damage, incorrect operational procedure, and weather-related and outside force. Examples of important combinations to explore are a combination of corrosion and mechanical damage, welds and natural forces (soil movement), etc. Once consensus is reached, a more robust treatment of interactive threats will be incorporated in the Kiefner/NYGAS risk model and information will be provided to upgrade other risk models.

Status - This research is being administered by NYSEARCH following an aggressive schedule with the investigative efforts being addressed by Kiefner Inc. The proposed completion date is mid-2012. It is recommended that the Energy Commission verify the completion of this NYSEARCH project and determine the potential for application in California.

Understanding Threat Interactions for Risk Analysis

The objective of this project is to increase the level of understanding related to threat interactions with a specific focus on risk determination for integrity management programs. The work in this project will provide a methodology for calculating the risk associated with a superimposed set of threats as well as a process for addressing unknown threats. Subpart O regulations and supporting standards such as ASME B31.8S provide guidance on individual threats and how they should be assessed. Although this same standard specifically mentions that threat interactions should be addressed, there is limited industry knowledge on the interactions of various threats and how they influence the overall risk of a segment of pipe. For example, a pipeline may exhibit an individual threat or even a combination of two threats that will not lead to a pipeline failure. However, couple the individual threat with another, or a combination with a third, and this may lead to a pipeline failure.

Status - This project is being executed by GTI and sponsored by OTD, PG&E, and the INGAA Foundation. The project is nearly complete resulting in a software based threat interaction model and methodology, as well as an operator guideline for its use. It is scheduled for completion in the summer of 2013.

Overarching Issues

4.2.4.1 Program Coordination

The need for an improvement in the coordination of the various integrity management R&D activities became evident in the early stages of data collection process during the interviews conducted in Task 2. This need was further emphasized during the workshop conducted during Task 3 with pipeline operators and representatives from not-for-profit R&D organizations. In

addition to the need to improve coordination between the organizations focused on natural gas R&D the coordination needs to include the coordination with other industries (rail, telco, defense, etc.) with a focus on transferring technologies that are currently used for other applications into the natural gas industry.

Having a common focus and establishing a methodology to learn from one another and share results are two techniques recommended for implementation by the Energy Commission.

Focus on Safety

All natural gas related research should improve safety. It is beneficial to increase efficiency, but the focus of R&D for the natural gas industry has been and should continue to be safety improvement. Public tolerance is nearly zero for incidents. One recommended strategy is to specifically look at the incidents from the last 10-20 years and ask the question, "If we had a technology to do _____, would it have prevented the incident?"

Lessons Learned and Technology Demonstration Workshop

It is recommended that the Energy Commission actively facilitate and sponsor an annual workshop where lessons learned can be shared and technologies can be demonstrated. Each workshop should be organized to allow a free exchange of information by the pipeline operators. Vendor participation should be by invitation only to provide information upon request. The recently conducted PHMSA R&D Forum provides one example of a successful format.

4.2.4.2 Education

The pipeline industry has programs that they regularly update to train their employees and inform the public. The recommended activities included in this section go beyond the current programs to assist the operating companies in their efforts to maintain a safe and reliable system.

Larger Resource Pool

Like many of the segments of the utility industry the transmission pipeline operators in California are experiencing the challenge of an aging workforce. The experience based judgment that has been the mainstay of the industry is or will soon be retiring. At one time the education system included degree programs aligned with the needs of the utility industry. However, due to industry downsizing and the minimization of hiring the demand for these talents declined with a corresponding decline in degree programs focused on the areas of specialty found in the industry. The result has been that there is a mismatch between the talent that is available and what is needed. Mercer's Workforce Sciences Institute addressed this topic for the natural gas industry in the August/September, 2012 issue of the American Gas Magazine[4] and recommended the following key jobs that the industry will need to fill based on its continued growth due to power generation and shale gas: experienced geoscientists, piping engineers, most environmental health and safety positions, process engineers, operational

[4] Taming the Talent Pipeline, H Nalbantian, P Tenenbaum and J Doherty, Mercer Workforce Science Institute, American Gas Magazine August/September, 2012

managers/supervisors, mechanics, welders, pipefitters, project managers and gas distribution engineers.

It is recommended that the Energy Commission partner with the university system in California to design and implement a degree program aligned with the needs of the utility industry of the future.

To initiate the partnership it is recommended that the Energy Commission work from a challenge list developed at the PHMSA R&D Forum in July, 2012 where a series of possible university project opportunities were suggested.

- Threat Detection from aerial platforms – specific issues not being addressed by current research / gap analysis
- Software development & tools to analyze/data mine information
- Industry Satellite
- Impact of land movement on pipe and its impact on high-impact areas
- ROW encroachment/maintenance surveillance technique improvements
- Multi-utility pipeline locator (one tool to locate multiple pipelines/utilities)

Among the needs to be addressed would be to have a documented process, training matrix and improved delivery format that would:

- Provide assistance in the training and retention of the existing workforce
- Capture of the experience base and useful application of the knowledge that resides within the workforce about to retire and transfer it to the next generation of practitioners
- The ability to communicate the needs of the industry to a new generation with different learning styles from those in the current workforce
- Provide the skill sets to implement the numerous emerging technologies described here and elsewhere that will impact the industry

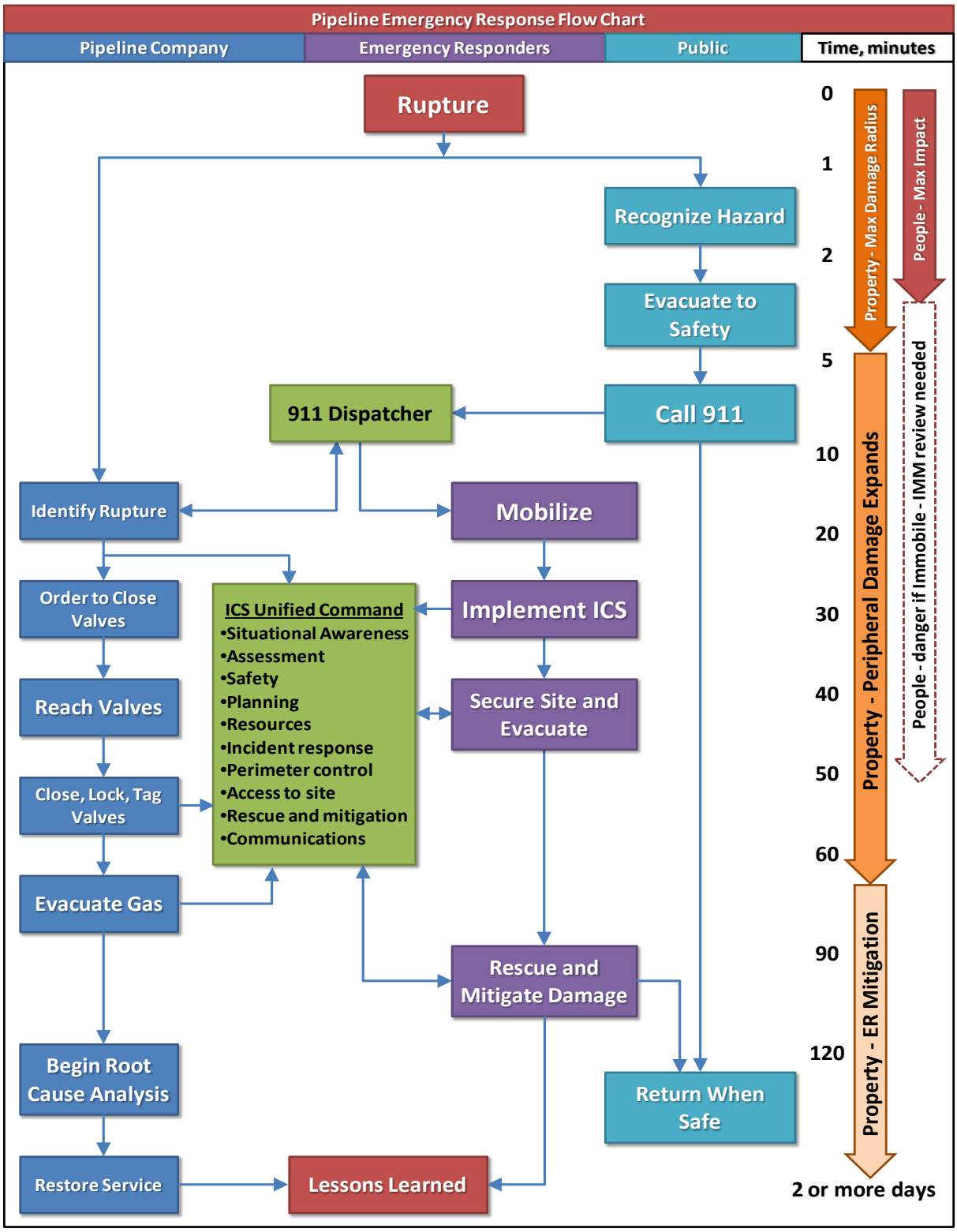
Improvements in Situational Awareness

Several types of improvements are envisioned regarding situational awareness to increase safety and improve incident response. People learn and respond to information in a variety of ways, some require a visual representation of the information others have to hear the information and there are also those that have to experience the situation. One approach to improving situational awareness is build off of information provided by INGAA. INGAA and their members are dedicated to the safe operation of the natural gas pipeline system with the goal of zero incidents. INGAA provides a wealth of information to assist the operators in

improving their communications efforts. By way of an example, INGAA responded[5] to the Notice of Public Comment issued in docket number PHMSA-2012-0021. The Notice was soliciting comments on the scope of the incident response study required to be conducted by the U.S. Comptroller General. INGAA's comments were directed at identifying particular topics that should be addressed in the study. Figure 5 below and the additional information provided in Appendix G provide an excellent resource that can be tapped to assist with preparing improvements in situational awareness.

[5] Pipeline Safety: Public Comment on Leak and valve Studies Mandated by the Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011, Docket No. PHMSA-2012-0021, INGAA response http://www.ingaa.org/File.aspx?id=18483

Figure 5: Natural Gas Pipeline Guidance on Emergency Response Time Reduction (April 27, 2012)



Source: INGAA

Primer on Integrity Management

Provide a primer on integrity management prepared by a non-industry author that includes pictorial as well as written explanations of what is involved in the normal operations and maintenance of a transmission pipeline followed by the steps to address an incident. The audience for a primer would include the full spectrum from emergency responders, to the public, to regulators to employees.

Situational Information

Improvements in this area would include the capability to provide mapping and system information to a variety of audiences in a manner that is interactive and readily understood. This situational information would include system maps, aerial photography and summary descriptions written in plain language such that audiences such as emergency responders and the public understand the incident and the necessary safety precautions. One example of an emerging technology with this type of emergency responder mapping capability is provided by PI Confluence, Inc. with their pipelinewatch.com software. Current capabilities allow the information to be accessed on-line; future accessibility will be provided via hand-held devices. http://piconfluence.com/pipelinewatch_mappingpage7.htm?utm_source=San+Francisco+AGA+R2+-+PipelineWatch.com&utm_campaign=San+Fran&utm_medium=email

Real Time Knowledge to the Situation – Video Link to Advisor

Use the existing communications technologies to link one or more expert advisors to the incident commanders via a real-time audio/video connection. A linkage of this type would maximize the technical capabilities that could be applied to any given incident in the shortest amount of time. This capability would have the potential to reduce the severity and extent of the incident and minimize the impact to human life and property.

4.2.4.3 Advocacy

Innovative Rate Recovery for New Technology Development

A variety of R&D rate recovery structures exist across the U.S. R&D is typically considered an operations and maintenance (O&M) expense that can be treated as simply as one of the many O&M expenses of the company or R&D expenditures can be handled using what is often termed a balance account. The placement of R&D under a balance accounting mechanism essentially restricts the use of the funds to R&D. Any unused funds from one year are carried forward to the next year with a balancing process occurring on a pre-established frequency of every so many years (ex. every five years). The California Public Utilities Commission (CPUC) has typically approved R&D as a line item expenditure, in the case of one of the operating companies funding for R&D for safety and distribution operations or end use was placed under a balance account. Additional requirements may be placed on the use of the R&D funds in the balance account, examples would include the requirement that the funds be used collaboratively or that the funds be used for projects that are focused on a specific type of technology development.

It is recommended that the Energy Commission consider supporting the creation of a balance accounting based R&D funding mechanism for all the natural gas pipeline operating companies in California.

Regulatory Acceptance of New Technologies

Advances in technology have been characterized as occurring at a pace such that we will experience more changes in the next ten years than we have experienced in the past 100 years. To emphasize that point as it relates to the energy industry, a utility regulator speaking at a recent conference on smart grid noted that advances in technology are occurring at a rate that is far faster than the ability of the regulatory community to keep up. For any emerging technology to become commercially available and termed to be used and useful it has to be proven and accepted with full support from the pipeline operator, the regulator and the manufacturer. It is recommended that a regulatory mechanism or process be established for introducing new assessment/remediation technology that is operator driven and initiated, inclusive of manufacturer and regulatory support, but can be accomplished in a reasonable time. Even though the development of a new technology is largely, but not exclusively an operator driven collaborative process that typically involves a manufacturer from the early stages, the regulator ultimately controls the pace of the acceptance of the technology.

This evaluation provided a descriptive summary of each recommended emerging technologies as they fit within the framework of a logical technology development and deployment strategy. This strategy emphasizes four primary needs, referred to throughout this chapter as strategic elements. First, before you can assess, monitor and manage a system you need to know what you have and where it is located, the emerging technologies needed to develop and maintain this capability are captured under the Asset Life Cycle Management – "What's Where" element. Concurrent with the need to completely understand the characteristics of the system is the need to be able to communicate and control the system. The strategic element System Communications and Control is used to capture these needs. This set of capabilities is followed by the requirements to assess and monitor the system, the strategic element System Monitoring and Assessment illustrates the technologies needed. The final strategic element is Overarching Issues that is used to capture a variety of needs and recommended activities spanning the entire integrity management process. Examples of these overarching issues would include the need for a focus on program coordination, education and advocacy for action on topics such as innovative rate recovery for the development of new technologies and once developed regulatory acceptance of the use of the new technologies. Together these four strategic elements identify the technology needs or gaps to be created or enhanced for the benefit of the California pipeline network.

Finally, this evaluation recommended a wide variety of technologies many of which result in improved communications and monitoring capabilities along with a strategy to integrate the use of the AMI communications backbone, currently being installed or enhanced in California, under the section that addresses system communications and control. The implementation of these recommended technologies along with this recommended strategy will provide a pathway to optimize the value of the AMI system and the performance of the pipeline monitoring and safety technologies.

CHAPTER 5: Implementation Plan

The Implementation Plan (Plan) addressed that segment of R&D directed at natural gas transmission pipeline assessment and monitoring for integrity management. Three previous tasks (described in Chapters 2 through 4, respectively) were used to effectively capture the current status of natural gas pipeline assessment and monitoring technologies used in California, compare those technologies to the full range of commercially available technologies and then identify emerging technologies that had the potential to improve the integrity management process.

The Plan focused the approach from the broad area of pipeline assessment to a technology development approach directed at addressing the root causes of pipeline incidents that lead to death, injury and/or property damage. The basis for this recommended approach is to focus the efforts of the Energy Commission on the development and deployment of technologies that would have the greatest potential to prevent incidents, mitigate the consequences should an incident occur and improve response time. The approach recommended maintains this focus while recognizing that there are considerable parallel efforts to improve best practices, update processes and procedures and limit right-of-way encroachment. These solutions are being actively and effectively addressed by others.

The identification of root causes comes from an assessment of past pipeline incidents as documented by the National Transportation Safety Board (NTSB). By focusing on actual incidents occurring on natural gas transmission pipelines that resulted in death, injury and/or property damage five major root causes emerged. The Plan recommends a technology development strategy for action by the Energy Commission to address each of these root causes.

5.1 NTSB Pipeline Accident Reports

The NTSB was established in 1967 as an independent agency of the United States Government responsible for the investigation of transportation accidents. To ensure that NTSB investigations focus on improving transportation safety the analysis of factual information and its determination of probable cause cannot be entered as evidence in a court of law. The NTSB issues a report following an investigation. A total of 114 pipeline accident reports have been issued to-date, the reports are summarized in Appendix H and are available on-line at http://www.ntsb.gov/investigations/reports_pipeline.html

Those accidents involving natural gas are a subset of the overall number with those involving transmission pipelines representing less than 18% of the total.

5.2 Plan Design

The recommended Plan consisted of a three phase program with each phase administered concurrently. A concurrent three phase approach is recommended to focus the resources of the Energy Commission thereby maximizing the potential to meet or exceed the Energy Commission goal of deploying technology within a 2 to 4 year timeframe.

Phase 1 consists of the successful completion of the project(s) to be initiated based on the Energy Commission solicitation of project proposals under PON 12-505 (described below). This accelerated effort to develop natural gas transmission pipeline assessment technologies was made possible as a result of recommended areas for technology development provided by GTI and UC Berkeley early in their respective projects.

Phase 2 consists of the Energy Commission actively participating in the development of the emerging technologies as recommended in the Task 4 report. The Task 4 report included summaries of 47 technologies in various stages of development that included a recommended level of involvement by the Energy Commission, along with a timeline and a priority. The emerging technology development roadmap included in the report is repeated in Appendix D for convenience, additional detail on each recommended technology is provided in the Task 4 report.

Phase 3 consists of a series of programs to be administered concurrently using PONs to address each of the five major root causes of pipeline incidents.

Phase 1: Energy Commission Solicitation

The first phase of the Plan occurred as PON-12-505, Pipeline Integrity Technology Demonstration Grant issued by the Energy Commission on November 2, 2012. The issuance of this PON was the result of Energy Commission sponsored workshop held on August 7, 2012. The contents of the workshop and the subsequent PON were based on preliminary information provided by GTI and UC Berkeley during the Energy Commission sponsored workshop. The information from GTI and UC Berkeley was based on the early stages of their assessment. The outcome of the PON was not known at the time of the preparation of the Plan.

Phase 2: Emerging Technology Development

The Task 4 report recommended a wide variety of emerging technologies many of which, if successful, will result in improved communications and monitoring capabilities along with a strategy to integrate the use of the AMI communications backbone, currently being installed or enhanced in California. The implementation of these recommended emerging technologies along with the recommended strategy will provide a pathway to optimize the value of the AMI system and the performance of the pipeline monitoring and safety technologies currently being considered or under development.

The Emerging Technology Development Roadmap included in the Task 4 report provided a summary of the recommended approach to be used for Phase 2 of the Plan (Appendix D). The Roadmap shows 47 projects or collaborative R&D programs recommended for consideration for participation or action by the Energy Commission. The roadmap shows each project on a development timeline, indicates the projects status (New, Proposed or Ongoing), the organization that is or will be controlling the work effort and the recommended priority (High, Medium or Low).

Phase 3: Addressing Root Causes

The Energy Commission has indicated that their interests are to identify technologies that can be quickly moved to being commercially available and to leverage and optimize the use of the

AMI system. The resources of every organization are limited and need to be optimized and focused to provide the greatest value. To that end, it is recommended that the greatest immediate benefit would be to focus the entire resources of the Energy Commission on the development of technology that goes beyond the broad area of pipeline assessment to a technology development approach to address the root causes of pipeline incidents. This recommended approach will focus the efforts of the Energy Commission on the development and deployment of technologies that would have the greatest potential to prevent incidents, mitigate the consequences should an incident occur and improve response time.

As noted earlier, the identification of root causes comes from an assessment of past pipeline incidents as documented by the NTSB. The assessment started with a review of the 114 NTSB Pipeline Accident Reports from 1969 thru 2012, summarized in Appendix H. By focusing on incidents on natural gas transmission pipelines that resulted in death, injury and/or property damage five major root causes emerged.

5.2.3.1 Root Causes

The top five major root causes for pipeline incidents resulting in death, injury or loss of property as determined by the NTSB can be summarized as:

- Failure to detect an existing defect. A defect may be the result of corrosion (internal or external), cracks dents or gouges, defective welds, or other anomalies.
- Poor data and record keeping over the life of the asset. This includes the full range of data from the time the pipe or appurtenance is manufactured, through construction and installation to operations and maintenance activity.
- Poor use of the data and records resulting in a lack of awareness of the presence or status of facilities as well as poor or low value analysis
- Failure to detect, locate, recognize and respond to a leak or rupture in a timely basis
- Poor response or lack of a coordinated response to an incident

5.2.3.2 Damage Reduction Groupings

The incident root causes identified above were placed in one of three damage reduction groupings that were felt to most strongly influence the reduction of death, injury or property damage. This summary is stated below in the form of areas in need of improvement:

Prevention of Failure

- Improve the capability to detect existing defects that may have been the result of manufacturing, construction or post-construction events
- Improve the records for the system from the point of manufacture through construction to operations and maintenance including inspections
- Improve analysis including data integration and modeling

Mitigation of Consequences

- Improve the capability to detect, locate and react to leaks/ruptures

Improvements in Response

- Improve information transfer, emergency response, and coordination

5.2.3.3 Technology Categories

The first step to provide a technology development and deployment pathway for the Plan was to link the damage reduction groupings and the associated root causes to the technology categories used to capture the commercially available and emerging technologies summarized in previous reports and described earlier.

Figure 6 was developed to capture the relationship between the damage reduction groups, the root causes and the technology categories.

Figure 6: Summary of Needs/Improvements Based on Incident Root Causes

Needs/Improvements Based on Root Causes	Technology Categories: Internal & external assessment & inspection methods	Long-term condition monitoring techniques	Risk-modeling and incident prediction tools	ROW encroachment & excavation damage prevention	Detection of pipeline leaks and ruptures	Remote stress/strain analysis of pipelines	Tools, techniques, and data analysis methods in IMP's	Nondestructive examination and analysis methods	Methods for system shutdown	System modeling of incident responses and shutdown	Data collection and communication technologies
Detection of Existing defects	X					X		X			
Records											X
Analysis			X				X	X			
Leak/Rupture Detection, Location, Minimize Release					X				X		
Rapid/Informed Coordination and Dispatch									X	X	X

Source: GTI

5.3 Program Opportunity Notices

Each damage prevention group and the associated root cause provide the basis for a technology development program with one or more PONs. Each PON should be fashioned to ensure that each proposal responding to the solicitation includes a clear pathway to market and that the attributes for success are fully addressed. In addition, each proposal should include the goal of providing meaningful and measureable improvements in existing technology, the acceleration of an emerging technology or the introduction of a technology not previously identified via this assessment project. Finally, it has been said that communications can never be too effective. To the extent possible and where applicable every PON would benefit from including an emphasis

on technologies that respond to the needs expressed by the PON through techniques that would leverage and optimize the use of the AMI systems in California.

It is recommended that the wording in the solicitation for each PON remain at a high level, base the need on what is known (the task reports) and what is needed (addressing the root cause). Leave the creativity of the PON response to the proposer.

Program: Prevention of Pipeline Failure

5.3.1.1 PON: Improving the Capability to Detect Existing Pipeline Defects

The technology development efforts of this PON should be focused on the enhancement of existing or the creation of new technology that builds off of those summarized under the categories of:

- Internal and External Assessment and Inspection Methods, Figure 11 and Figure 12 (see Appendix I).
- Remote Stress/Strain Analysis of Pipelines, Figure 13 and Figure 14 (see Appendix I).
- Nondestructive Examination and Analysis Methods, Figure 15 and Figure 16 (see Appendix I).

Broad based needs descriptions that could be used in a PON to improve the capability to detect existing pipeline defects would include but not be limited to the need for:

Material Characterization Tools

Tools of this type would allow the determination of pipe material characteristics to validate records that are not comprehensive, traceable, complete, and/or validated. Tremendous benefit would be realized if properties such as yield strength, fracture toughness, ductility, and chemistry (in effect grade validation) could be validated and/or determined from internal inspection tools. Further, there is a need to identify small, "pup" sections of pipe that could have significantly different material characterizations and weld quality as compared to the mainline pipe sections. There are some material characterization tools, such as magnetic flux leakage and stress-strain microprobes, that could be incorporated onto in-line platforms, but further development and validation is needed.

Improving Magnetic Flux Leakage (MFL)

MFL sensor technology has continued to improve to provide increased levels of accuracy and precision, however there remains a need to increase the sizing capabilities and to increase the probability of identification and the probability of detection.

Platforms for Guided Wave Ultrasonic Technology (GWUT)

GWUT is a promising technology for detecting and characterizing planar defects that cannot be addressed with MFL. There is a need to develop an internal inspection platform that can transport GWUT sensors with the potential to add UT sensors for enhanced characterization. GWUT could then be used as an internal screening tool, with in-situ validation by standard UT measurements (line of sight).

Radiography by Selective Detection – RSD X-Ray

RSD X-Ray is a promising technology under development for characterizing, detecting and quantifying material defect and features for both metallic and non-metallic pipelines. It provides in-situ, near real time information and can potentially be implemented on various pigging platforms. This technology requires further and accelerated development.

Acoustic Resonance Technology (ART) Development and Testing

ART is promising for detecting and characterizing volumetric defects in gas pipes (without the need for a liquid couplant) that cannot be addressed with MFL. However, the technology needs further development, testing, and validation.

Hydrotest Equivalent Inspection Tool

In addition to material characterization tools, there is a need for inspection and assessment tools that could find stable manufacturing (mill) and construction defects that would fail a construction hydrotest. Such tools may remove the need for a newly required, post-construction hydrotest of legacy pipe that has been in service for decades.

Dent and Deformation Characterization Tool

MFL tools provide adequate detection of most dents, but there is a need for improved strain characterization of dents and deformations, particularly for re-rounded and/or minor dents where the profile is not representative of the whole strain history. The stresses and potential cracking from these minor dents could act as crack initiators that could ultimately grow from cyclical loads and stresses.

Geomechanical Strain Detection

Earth movement and other external stresses that result in pipe axial strains are difficult to detect with existing ILI tools in a single run. There is a need for a sensor that can detect residual strains. Legacy acetylene-based girth welds are of particular concern in the presence of enlarged axial stresses and strains.

5.3.1.2 PON: Improving the Records Used for Pipeline Asset Lifecycle Management

The technology development efforts of this PON should be focused on the enhancement of existing or creation of new technology that builds off of those summarized under the technology category of:

- Data Collection and Communications Technologies, Figure 17 and Figure 18 (see Appendix I).

A broad based needs description that could be used in a PON to improve the records would include but not be limited to the following. There is a need for a system that would provide operators with the ability to track assets from manufacturing through replacement while geospatially associating engineering and operational data to specific assets. The proposed system should be capable of assisting operators in the compliance with integrity management regulations by providing operators the capability of identifying and tracking component

performance by monitoring failures over time. This information will allow operator to identify potentially faulty components and understand risk profiles to assist in making repair and replacement decisions. The proposed system(s) should address the use of standardized methods to record material and manufacturing properties, use tracking a traceability encoding, maximize the use of a records management and data base integration system and include techniques to enhance field data capture.

5.3.1.3 PON: Improving the Data Analysis Used for Pipeline Integrity Management

The technology development efforts of this PON should be focused on the enhancement of existing or creation of new technology that build off of those summarized under the technology categories of:

- Risk Modeling and Incident Prediction Tools, Figure 19 and Figure 20 (see Appendix I).
- Tools, Techniques and Data Analysis Methods in IMP's, Figure 21 and Figure 22 (see Appendix I).
- Nondestructive Examination and Analysis Methods, Figures 11 and 12 (see Appendix I).

A broad based needs description that could be used in a PON to improve data analysis would include but not be limited to the need for the development and deployment of:

Industry Database for Pipeline Integrity Management

Data analysis and modeling improve based on the quantity and quality of the data available. Individual pipeline operators have data representative of their specific system which has value; however, the value could be improved with access to additional high quality data from other pipeline operators. This PON is focused on the first phase of improving data analysis and modeling for pipelines through the creation of an industry database of data from integrity management programs which is then made available to others providing a larger database that could be used for trend analysis and threat identification. While being straightforward in concept the approach has numerous pitfalls that must be overcome to be able to provide a database that is used and useful. The proposer must provide a strategy design that identifies each pitfall and provides a realistic path to a successful result.

Predictive Performance Based Model for Pipeline Integrity Management

This model development effort is envisioned to provide a programmatic (proactive) decision making methodology for integrity management to improve upon the existing prescriptive (reactive) man-made method for pipeline integrity management. The predictive performance based modeling tool would integrate the individual operator data, and if available data from an industry database, to be able to make an effective decision or have it direct you programmatically to where an operator should focus their concern. The benefit of this type of improvement relates to the continuing search for safety and efficiency improvements as well as to supplement the man-made reactive decision making process.

Real Time System Control Model

Technologies to automate, sense, monitor, control and communicate are advancing at a rapid rate. Power requirements are being reduced, and systems are being miniaturized and made available by a wide variety of providers at a lower cost. Concurrent with these advances a variety of communications platforms are being installed and made available for AMI by both public providers and private companies. This PON is focused on the development of real time modeling systems to provide new or enhanced ways to control the pipeline utilizing an on-line analysis tool to model the system using real-time data to gain intelligence and identify risks as they develop.

Program: Mitigation of Consequences from Pipeline Incidents

5.3.2.1 PON: Improving the Capability to Detect, Locate, and React to Pipeline Leaks/Ruptures

The technology development efforts of this PON should be focused on the enhancement of existing or creation of new technology that build off of those summarized under the technology categories of:

- Detection of Pipeline Leaks and Ruptures, Figure 23 and Figure 24 (see Appendix I).
- Methods for System Shutdown, Figure 25 and Figure 26 (see Appendix I).

Broad based needs descriptions that could be used in a PON to mitigate the consequences from a pipeline incident would include but not be limited to the need for:

Improved Detection of Pipeline Leaks and Ruptures

New or enhanced technologies to improve the detection, locating and pinpointing of a leak or rupture of a pipeline transporting natural gas are being sought for study. Technology developments must demonstrate the capability to better detect and pinpoint a leak or rupture, reduce the incidence of false alarms and improve safety while providing an operational advantage associated with the cost of installation, operation and maintenance of the proposed system when compared to existing technology.

Improved Methods for system Shutdown

This PON is focused on the development of more accurate line leak/line break detection system that improves communications, reduces or eliminates false alarms and minimizes unintended valve closures while safeguarding public health and safety. Automated shut-off valves have the capability to minimize the time required to stop the flow of natural gas once a leak or rupture has been detected limiting the impact on life and property. However, the automatic closure of a valve on a line due to a false alarm creates operational and societal problems and unnecessary costs.

Program: Improvements in Response to Pipeline Incidents

5.3.3.1 PON: Improving Pipeline Incident Coordination and Response

The technology development efforts of this PON should be focused on the enhancement of existing or creation of new technology that build off of those summarized under the technology categories of:

- Methods for System Shutdown, Figure 25 and Figure 26 (see Appendix I).
- System Modeling of Incident Response and Shutdown, Figure 27 (see Appendix I).
- ROW Encroachment and Excavation Damage Prevention, Figure 28 (see Appendix I).
- Data Collection and Communications Technologies, Figure 17 and Figure 18 (see Appendix I).

In May, 2012 INGAA submitted comments in response to the Notice of Public Comment issued in the PHMSA docket number PHMSA-2012-0021 that was focused on the scope of an incident response study of the ability of pipeline operators to response to a release of natural gas. INGAA's comments stressed six opportunities for time savings that could be addressed during incident mitigation, management and response based on how operators recognize and respond to an incident, these include how operators:

- Detect failures
- Place and operate valves
- Evacuate natural gas from pipeline segments
- Determine their priorities in coordination efforts with emergency responders
- Mitigate an incident's immediate consequences
- Mitigate an incident's broader impact on other customers' supply

Many of the recommendations are focused on steps to create and implement plans and procedures, educating the public and emergency response personnel and providing training. Those efforts are being actively and effectively addressed by others. The broad based needs descriptions that could be used in a PON to improve the response to pipeline incidents through the creation or enhancement of technology would include but not be limited to the need for:

Improvements in Situational Information

Develop technology capable of providing mapping and pipeline infrastructure information to a variety of audiences in a manner that is interactive and readily understood. This situational information would include system maps, aerial photography and summary descriptions written in plain language such that audiences such as emergency responders and the public understand the incident and the necessary safety precautions.

Real Time Knowledge to the Situation – Video Link to Advisor

Use the existing communications technologies and/or the AMI to link one or more expert advisors to the incident commanders via a real-time audio/video connection. A linkage of this type would maximize the technical capabilities that could be applied to any given incident in the shortest amount of time. This capability would have the potential to reduce the severity and extent of the incident and minimize the impact to human life and property.

The information presented in Figure 11 through Figure 28, found in Appendix I, represent a summary of the technologies in the respective category identified through a review of publically available information. Reference is made to the technologies summarized in each figure to provide examples of technologies to enhance or use as the basis for the creation of a new technology.

5.4 Schedule and Priority

The Plan assumed that Phase 1 efforts were underway and that Phase 2 efforts could be initiated by the end of the second quarter of 2013. It was recommended that the creation and issuance of PONs to address the root causes described in Phase 3 occur in parallel with the Phase 1 and 2 efforts with the first round of PONs being issued no later than the third quarter of 2013. The timing of the individual projects within each program will be established based on the scope of work of each approved and contracted project.

A commitment of dedicated resources by the Energy Commission will be required to complete all three phases of the recommended three phased Plan within the specified timeframe of 2 to 4 years. Completion of Phases 1 and 2 are attainable given that PON 12-505 is already underway and the effort associated with the recommended involvement of the Energy Commission in the various emerging technology development activities described in Task 4 could be accomplish without a formal PON process. It is worthy of note that the anticipated deliverables of Phase 1 and the selective participation by the Energy Commission in the ongoing and new projects recommended in Task 4 via the Phase 2 effort could be directed to provide meaningful technologies to address the root causes that serve as the core for Phase 3.

The concurrent administration of Phase 3 with Phases 1 and 2 presents the greatest challenge. Ideally, equal emphasis should be dedicated to addressing each of the five root causes described under Phase 3 of the Plan. However, it is reasonable to assume that either financial resources, staffing or both may be limited. To optimize the potential for meaningful results from Phase 3 it is recommended that the highest priority be directed at the enhancement or creation of technologies that would improve the capability to prevent a pipeline failure. Should resources be available to go beyond the development and deployment of failure prevention technologies efforts should be dedicated to improvements that would mitigate the consequences should a failure occur. Of the three efforts to address root causes the lowest priority would be the improvement of response to an event.

APPENDIX A:
List of Acronyms

ACVG – Alternating Current Voltage Gradient
AGM – Above Ground Markers
AI – American Innovations Ltd.
ALPIS – Airborne LIDAR Pipeline Inspection System
AMI – Advanced Metering Infrastructure
APDM – ARCGIS Pipeline Data Model
API – American Petroleum Institute
ART – Acoustic Resonance Technology
ASME – American Society of Mechanical Engineers
ASTM – American Society for Testing and Materials
BEM – Broadband Electromagnetic Technology
CEC – California Energy Commission
CFR – Code of Federal Regulations
CGA – Common Ground Alliance
CGI – Combustible Gas Detector
CO_2 – Carbon Dioxide
CP – Cathodic Protection
CPUC – California Public Utilities Commission
CTOD – Crack Tip Opening Displacement
CUI – Corrosion under Insulation
DA – Direct Assessment
DAC – Data Amplitude Curve
DCVG – Direct Current Voltage Gradient
DOT – U.S. Department of Transportation
DPI – Dye Penetration Inspection
DRAM – Dynamic Risk Analysis and Management
DSP – Digital Signal Processing
ECA – Engineering Critical Assessment
ECDA – External Corrosion Direct Assessment
ECOL – Electrical Conductivity Object Locator
EEN – Excavation Encroachment Notification
EFV – Excess Flow Valve
EGS – Excavation Guidance System
EM – Electron Microscopy
EMAT – Electromagnetic Acoustic Transducer
EMW-C – Electromagnetic Wave - Corrosion
EPOF – European Pipeline Operators Forum
ER – Electrical Resistance (probes for corrosion monitoring)
FERC – Federal Energy Regulatory Commission
FRASTA – FRActure Surface Topography Analysis

FID – Flame Ionization Detector
FLIR – Forward Looking Infrared
GC – Gas Chromatograph
GE – General Electric
GIS – Geographical Information System
GMFL – Gas MFL
GTI – Gas Technology Institute
GTN – TransCanada's Gas Transmission Northwest System
GPR – Ground Penetrating Radar
GPS – Global Positioning System
GTT – Grid Tech Team
GSM – Global System for Mobile Communications
GSTC – Gas Storage Technology Consortium
GUL – Guided Ultrasonic Limited
GWT – Guided Wave Technology
HCA – High Consequence Area
HC Gases – Hydrocarbon gases such as benzene, toluene, xylene, methane, ethane etc.
HDD – Horizontal Directional Drilling
HDL – High Desert Lateral operated by KRGT
HF – High Frequency
HIC – Hydrogen Induced Cracking
HMI – Human Machine Interface
H_2O - Water
HR – High Resolution
H_2S – Hydrogen Sulfide
ICDA – Internal Corrosion direct Assessment
ICS – Incident Command System
ID – Inside Diameter
IEEE – Institute of Electrical and Electronics Engineers
ILI – In-Line Inspection
IMP – Integrity Management Program
IPC – International Pipeline Conference
IT – Information Technology
IUI - Intelligent Utility Installation
KRGT – Kern River Gas Transmission Company
Ksi – Kips per Square Inch (A kip is a non-SI unit of force. It equals 1,000 pounds-force, used primarily by American architects and engineers to measure engineering loads.)
LCD – Liquid Crystal Display
LDC – Local Distribution Company
LIDAR – Light Detection and Ranging
LPI – Liquid Penetration Inspection
LPR – Linear Polarization Resistance
MAOP – Maximum Allowable Operating Pressure

MDT – Minimum Detection Threshold
MFL – Magnetic Flux Leakage
MIC – Microbiologically Influenced Corrosion
MIR – Micropower Impulse Radar
MJL – Magnetic Joint Locator
MMcf/d – Million Cubic Feet per Day
MPI – Magnetic Particle Inspection
NACE – National Association of Corrosion Engineers
NDE – Non-Destructive Evaluation
NDI – Non-Destructive Inspection
NDT – Non-Destructive Testing
NGA – Northeast Gas Association
NYSEARCH – Northeast Gas Association's research and development organization
OD – Outside Diameter
OMD – Optical Methane Detector
OPS – Office of Pipeline Safety, U.S. Department of Transportation
OTD – Operations Technology Development, NFP
PDP – Previously Damaged Pipe
PG&E – Pacific Gas and Electric
PHMSA – Pipeline and Hazardous Materials Safety Administration
PoD – Probability of Damage
POD – Probability of Detection
PoF – Probability of Failure
PIMS – Permanently Installed Monitoring System
PLC – Programmable Logic Controller
P&M – Preventative and Mitigative
PR – Public Relations
PRCI – Pipeline Research Council International
P/S Potential - Pipe-to-Soil voltage potential
PSI – Physical Sciences Inc.
RBI – Risk Based Inspection
R&D – Research and Development
RFI – Radio Frequency Imaging
RFID – Radio Frequency Identification
RIPL – Risk Intelligence Platform
ROW – Right of Way
RSD X – Ray – Radiography by Selective Detection X-Ray
RT – Radiographic Technology
RTTM – Real Time Transient Model
RTU – Remote Terminal Unit
S/A – Soil to Air Interface
SBIR – Small Business Innovation Research

SCADA – Supervisory Control and Data Acquisition (Pipeline flow and pressure monitoring and control systems)
SCC – Stress Corrosion Cracking
SCCDA – Stress Corrosion Cracking Direct Assessment
SDG&E – San Diego Gas & Electric
SME – Subject Matter Expert
SMUD – Sacramento Municipal Utility District
SMYS – Specified Minimum Yield Strength
SoCalGas – Southern California Gas
SR – Standard Resolution
SFAI – Swept Frequency Acoustic Interferometry
TCG – Time-Controlled Gain
TDW – T D Williamson
TFI – Transverse Field Inspection
TIS – Terahertz Imaging Spectroscopy
TPD (IF) – Third Party Damage (instantaneous/immediate failure)
UC Berkeley – University of California at Berkeley
USDOE – United States Department of Energy
UT – Ultrasonic Testing
VOC – Volatile Organic Compound
WAN – Wide Area Network
WPA – Wireless Protected Access
WT – Wall Thickness

APPENDIX B:
Glossary of Terms

The following terms are used when discussing pipeline testing and monitoring technologies. This Glossary is intended as a reference. Terms are not necessarily used within this report.

Aboveground Marker (AGM): A portable device placed on the ground above a pipeline that both detects and records the passage of an in-line inspection tool or transmits a signal that is detected and recorded by the tool.

Acoustic Resonance Technology (ART): Ultrasonic circuit tuned to resonate with changing time of flight to measure distance.

Anomaly: A possible deviation from sound pipe material or weld. Indication may be generated by nondestructive examination, such as in-line inspection.

ASME B 31G: "Manual for Determining the Remaining Strength of Corroded Pipelines: A Supplement to ASME B31 Code for Pressure Piping," published by ASME International. This is commonly used when analyzing metal-loss anomalies in pipe.

B-Scan: A cross-sectional display of a test object formed by plotting the beam path lengths for echoes with a preset range of amplitude, in relation to the position of beam axis (in ultrasonic testing), or the values of the measured magnetic field (with magnetic flux leakage), as the probe is scanned in one direction only.

Batch, Batching: Separated volume of liquid within a liquids pipeline or of liquid within a gas pipeline. Sealing (batching) pigs are typically used for separation.

Bellhole: An excavation to permit a survey, inspection, maintenance, repair, or replacement of pipe sections.

C-Scan: A two-dimensional plane display of a test object formed by plotting the presence of echoes within a preset range of amplitude, a beam path length (in ultrasonic testing), or the values of the measured magnetic fields (with magnetic flux leakage), in relation to the position of the scanning probe.

Calibration Dig: Exploratory excavation to validate findings of an in-line inspection tool with the purpose of improving data interpretation.

Caliper Pig: See *Geometry Pig*.

Camera Pig: A configuration pig that carries a video or film camera and light source(s) for photographing the inside surface of a pipe on an intermittent, real-time, or continuous basis.

Cathodic Protection (CP): A technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

Characterize: To qualify the type, size, shape, orientation, and location of an anomaly.

Check Valve: Valve that prevents reverse flow. Can cause damage to in-line inspection tools if not fully opened.

Class Location: A criterion for pipeline design set by the United States Code of Federal Regulations, Title 49, Part 192.17 Class 1 is rural and Class 4 is heavily populated. A class location is based on the number and type of buildings situated in an area that extends 220 yd (200 m) on either side of the centerline of any continuous 1.0-mile (1.6-km) length of a gas pipeline.

Classify: To separate indications into categories, e.g., anomalies, nonrelevant indications, pipeline components, etc.

Cleaning Pig: A utility pig that uses cups, scrapers, or brushes to remove dirt, rust, mill scale, and other debris from the pipeline. Cleaning pigs are utilized to increase the operating efficiency of a pipeline or to facilitate inspection of the pipeline.

Coating Disbondment: The loss of adhesion between a coating and the substrate.

Coil Sensor: See *Induction Coil*.

Corrosion: The deterioration of a material, usually a metal, that results from a reaction with its environment.

Crack Coalescence: Joining of two or more cracks in close proximity to form a longer crack.

Crack, Cracking: Very narrow elongated defects caused by mechanical splitting into parts.

Critical Defect: A defect for which an analysis indicates that immediate attention is required.

Data Analysis: The process through which indications recorded in an in-line inspection are evaluated to classify, characterize, and size them.

Defect: An anomaly for which an analysis indicates that the pipe is approaching failure as the nominal hoop stress approaches the specified minimum yield stress of the pipe material.

Detect: To sense or obtain a measurable in-line inspection indication from an anomaly in a pipeline.

Differential Pressure: The difference between the pressures behind and ahead of the in-line inspection tool – the actual propeller of the tool.

Diffusion: The passage of a substance into a body (e.g., hydrogen into steel).

Dirty Steel: A term used to denote steel containing a high number of nonmetallic inclusions.

Discrete Repair: A short segment of pipeline identified to be repaired.

Dissolution: The decomposition of a solid into parts.

Distribution Line: A gas pipeline other than a gathering line or transmission line (See U.S. Code of Federal Regulations, Title 49, Part 192).

Double Submerged Arc Weld (DSAW): Weld using filler metal passes on the inside and outside of the pipe.

Ductility: A measure of the capability of a material to be deformed plastically before fracturing.

Dummy Tool Run: Preliminary run of an un-instrumented pig to verify safe passage of a fully instrumented tool through a section of pipeline. Dummy runs can also be used to remove debris from the inside of the pipeline.

Elastic Limit: The maximum stress to which a material may be subjected without retention of any permanent deformation after the stress is removed.

Electric Potential: A voltage existing between the pipe and its environment.

Electric Resistance Weld (ERW): Weld formed by resistance heating of the two edges of a pipe and then forcing them together to create a solid-state weld.

Estimated Repair Factor (ERF): The ratio of the pipeline design pressure to the "safe maximum pressure" as determined by an analysis criterion (e.g., ASME B 31G, RSTRENG).

Evaluation: A review, following the identification of an anomaly, to determine whether the anomaly meets specified acceptance criteria.

False Call: An inspection indication that is erroneously classified as an anomaly or a defect.

Fatigue: The phenomenon leading to fracture of a material under repeated or fluctuating stresses having a maximum value less than the tensile strength of the material.

Feature: As used in this text, any physical object detected by an in-line inspection tool during the performance of an inspection run. Features may be anomalies or indications, pipeline valves and fittings, nearby metallic objects, or other items.

Flash Welded: Distinct type of electric resistance weld (ERW) pipe, made from individually rolled plates formed into cans before being welded.

Fracture Mechanics: A quantitative analysis for evaluating structural reliability in terms of applied stress, crack length, and specimen geometry.

Fracture Toughness: A measure of the resistance of a material to defect extension, either slow or rapid.

Free Corrosion Potential: The electric potential that exists in the absence of an applied potential with corrosion occurring.

Free Surface: A surface with one side not constrained by adjacent metal, just air.

Gathering Line: A pipeline that transports gas from a production facility (e.g., gas, well) to a processing or compressor station prior to entry into the transmission pipeline.

Gauge Plate/Bend Plate Pig: A utility pig mounted with a flexible metal plate of a specified diameter less than the minimum internal diameter of the pipeline. Pipe bore restrictions less than the plate diameter or short radius bends will permanently deflect the plate material.

Gel Pig: A utility pig that is composed of a highly viscous gelled liquid, often used for pipeline cleaning.

Geometry Pig: A configuration pig designed to record conditions, such as dents, wrinkles, ovality, bend radius and angle, and occasionally indications of significant internal corrosion, by sensing the shape of the internal surface of the pipe.

Girth Weld: Circumferential weld joining two joints of pipe.

Hall-Effect Sensor, Hall Element: A type of sensor that directly measures magnetic field. Hall-effect sensors require power to operate.

High Vapor-Pressure (HVP) Liquid: Hydrocarbons or hydrocarbon mixtures in the liquid or quasi-liquid state with a vapor pressure in excess of 107 kPa (15.5 psi) absolute at 38°C (100°F).

Holiday: A discontinuity in a protective coating that exposes unprotected surface to the environment.

Hoop Stress: Stress around the circumference of a pipe (i.e., perpendicular to the pipe length) caused by internal pressure.

Hydrogen Embrittlement: A loss of ductility of a metal resulting from absorption of hydrogen.

Hydrolysis: Decomposition of a chemical compound by reaction with water.

Hydrostatic Testing (Re-Testing): Testing of sections of a pipeline by filling the line with water and pressurizing it until the nominal hoop stresses in the pipe reach a specified value.

Imperfection: An anomaly in the pipe that will not result in pipe failure at pressures below those that produce nominal hoop stresses equal to the specified minimum yield stress of the pipe material.

Incident: An event that is reported to U.S. Department of Transportation, Office of Pipeline Safety, that involves fatalities, injuries, property damage in excess of $50,000, unintentional release of natural gas, customer outages, or other conditions that, in the opinion of the pipeline operator, are significant enough that they should be reported.

Indication: A finding of a nondestructive testing inspection.

Induction Coil: A type of sensor that measures the time rate of change in magnetic flux density. Induction coils do not require power to operate, but have a minimum inspection speed requirement.

In-Line Inspection (ILI): The inspection of a pipeline from the interior of the pipe using an in-line inspection tool. Also called *Intelligent* or *Smart Pigging*.

In-Line Inspection Tool: The device or vehicle that uses a nondestructive testing technique to inspect the pipeline from the inside. Also known as *Intelligent* or *Smart Pig*.

Instrumented Pig Tool: Older term for in-line inspection tools.

Interaction Rules: Specifications that establish spacing criteria between anomalies or defects. If the indications or defects are proximate to one another within the criteria, the anomaly or defect is treated as a single larger unit for engineering analysis purposes.

Intergranular Crack: Crack growth or crack path that is between the grains of a metal.

Joint: A single section of pipe that is welded to others to make up a pipeline.

Launcher: A pipeline device used to insert a pig into a pressurized pipeline.

Leak: A small opening, crack, or hole in a pipeline causing some product loss, not necessarily immediately impairing the operation of the pipeline.

Liquefied Natural Gas (LNG): Natural gas liquefied by refrigeration or pressure in order to facilitate storage or transport.

Liquefied Petroleum Gas (LPG): Petroleum gases (butane, propane, etc.) liquefied by refrigeration or pressure to facilitate storage or transport.

Loading Rate: Rate at which pressure increases in a pipeline.

Longitudinal Channeling: Narrow, deep (channel-like), axially oriented corrosion, often along a longitudinal seam weld.

Low Vapor-Pressure (LVP) Liquid: Hydrocarbons or hydrocarbon mixtures in the liquid or quasi-liquid state with a vapor pressure of 107 kPa (15.5 psi) absolute or less at 38°C (100°F).

Lorentz Forces: Forces acting on moving charges in magnetic fields.

Magnetic Field Strength: The magnitude of the magnetic field produced by a magnet.

Magnetic Flux Leakage (MFL): The flows of flux from a magnetized material, such as the wall of a pipe, into a medium with lower permeability, such as gas or air.

Magnetic Flux Lines: A representation of the strength and direction of a magnetic field. Flux lines are drawn parallel to the direction of magnetic force. The spacing of these lines represents the magnetic field strength. Flux lines always form nonintersecting closed loops starting at the north pole and ending at the south pole of a magnet.

Magnetic Particle Inspection (MPI): A nondestructive examination technique for locating surface flaws in steel using fine magnetic particles and magnetic fields.

Magnetic Permeability: The ability of magnetic flux to diffuse through (or permeate) a magnetic material. The ratio of magnetic flux density to magnetic field strength.

Magnetic Saturation: The degree of magnetization at which a further increase in magnetic field strength produces a decrease in magnetic permeability of a material.

Mapping Pig: A configuration pig that uses inertial sensing or some other technology to collect data that can be analyzed to produce an elevation and plan view of the pipeline route.

Maximum Allowable Operating Pressure (MAOP): The maximum internal pressure permitted during the operation of a pipeline as defined by the U.S. Code of Federal Regulations.

Maximum Operating Pressure (MOP): The maximum internal pressure that cannot normally exceed the maximum allowable operating pressure expected during the operation of a pipeline.

Metal Loss: Any of a number of types of anomalies in pipe in which metal has been removed from the pipe surface, usually due to corrosion or gouging.

Microstructure: Structure of metals and alloys as revealed after polishing and etching; hot-rolled steels usually consist of bands of ferrite (iron) and pearlite (carbon) but may contain other microstructures such as martensite (hard brittle grains) or bainite (not as hard or brittle as martensite).

Mill Scale: The oxide layer formed during hot fabrication or heat treatment of metals.

Nondestructive Evaluation (NDE): The evaluation of results from nondestructive testing methods or nondestructive testing techniques in order to detect, locate, measure, and evaluate anomalies.

Nondestructive Testing (NDT): The actual application of a nondestructive testing method or a nondestructive testing technique.

Nondestructive Testing Method (NDT Method): A particular method of nondestructive testing, such as radiography, ultrasonic, magnetic testing, liquid penetrant, visual, leak testing, eddy current, and acoustic emission.

Nondestructive Testing Technique (NDT Technique): A specific way of utilizing a particular nondestructive testing method that distinguishes it from other ways of applying the same nondestructive testing method. For example, magnetic testing is a nondestructive testing method while magnetic flux leakage and magnetic particle inspection are nondestructive testing techniques. Similarly, ultrasonic is a nondestructive testing method, while contact shear-wave ultrasonic and contact compression-wave ultrasonic are nondestructive testing techniques.

Nonmetallic Inclusion: A particle of foreign material in a metallic matrix. Usually the foreign material is an oxide, sulfide, or silicate, but may be of any substance foreign to the matrix.

Nonrelevant Indication: A response recorded during an inspection that comes from a source outside the pipeline, such as foreign objects in the ditch.

Nucleate: Initiate the growth of a crack.

Off-Line Inspection: Inspection of a pipeline section that is removed from service.

On-Line Inspection: Inspection of a pipeline section while it is in service.

Passivity: The state of being passive. For the purpose of this report, a function of the electrochemical environment involving formation of a passive or protective film.

pH: For the purpose of this report, a measure of the acidity or alkalinity of a substance.

Pig: A generic term signifying any independent, self-contained device, tool, or vehicle that moves through the interior of the pipeline for inspecting, dimensioning, or cleaning.

Pig Sig: A usually mechanical sensor on the pipe activated by the passage of the in-line inspection tool.

Pigging: See *In-Line Inspection*.

Pipeline: That portion of the pipeline system between compressor or pump stations including the pipe, protective coatings, cathodic protection system, field connections, valves, and other appurtenances attached or connected to the pipe.

Pipeline Component: A feature, such as a valve, cathodic protection connection, or tee that is a normal part of the pipeline. The component may produce an indication that is recorded as part of an inspection by an in-line inspection tool or configuration pig.

Pipeline System: All portions of the physical facilities through which gas, oil, or product moves during transportation, including pipe, valves, and other appurtenances attached to the pipe, such as compressor units, metering stations, regulator stations, delivery stations, holders, and other fabricated assemblies. (See U.S. Code of Federal Regulations, Title 49, Part 192.)

Pressure: Level of force per unit area exerted on the inside of a pipe or vessel.

Pressure Reversal: Failure of a defect (e.g., crack) at a pressure level below the maximum level reached on a prior loading (e.g., hydrostatic retest).

Proportional limit: See *Elastic Limit*.

Receiver: A pipeline facility used for removing a pig from a pressurized pipeline.

Remediation: An operation or procedure that eliminates the factor, or factors, causing an imperfection, defect, or critical defect.

Remnant Magnetization: The magnetization level left in a steel pipe after the passage of a magnetic in-line inspection tool.

Residual Stress: Stress present in an object in the absence of any external loading; results from manufacturing process, heat treatment, or mechanical working of material.

RSTRENG: Analysis criterion specified in the American Gas Association project report AGA-PR-3-805,19 "A Modified Criterion for Evaluating the Remaining Strength of Corroded Pipe."

RESTRENG 2: An enhanced version of RSTRENG as specified in the American Gas Association project report AGA-PR-218-9205.

Rupture: The instantaneous tearing or fracturing of pipe material causing large-scale product loss and immediately impairing the operation of the pipeline.

Rupture Pressure Ratio (RPR): The ratio of the "predicted burst pressure" calculated by an analysis criterion (e.g., ASME B 31G, RSTRENG, etc.) to the pressure at specified minimum yield stress (SMYS).

Stress Corrosion Cracking Direct Assessment (SCCDA): As defined in the NACE Standard RP0204-2004, Stress Corrosion Cracking (SCC) is the cracking of material produced by the combined action of corrosion and tensile stress (residual or applied). SCC Direct Assessment Methodology is a procedure that can identify areas where either near-neutral-pH SCC or high-pH SCC can occur on external pipe surfaces. The SCCDA process consists of four Steps: Pre-assessment, Indirect Inspection, Direct Examination and Post Assessment.

Seam Weld: The longitudinal weld in pipe, which is made in the pipe mill.

Selective Pipe Replacements: Pipe replacements undertaken adjacent to critical areas such as dwellings.

Sensors: Devices that receive a response to a stimulus, e.g., an ultrasonic sensor detects ultrasound.

Shielded Corrosion: Corrosion between the pipe and the protective coating, which is not controlled by cathodic protection currents. Commonly referred to as "cathodic shielding."

Slug: Confined liquids within a gas pipeline.

Smart Pig: See *In-Line Inspection Tool*.

Sour Gas: Natural gas containing hydrogen sulfide in such proportion as to require treating in order to meet domestic sales gas specifications.

Specified Minimum Yield Strength (SMYS): A required strength level that the measured yield stress of a pipe material must exceed, and which is a function of pipe grade. The measured yield stress is the tensile stress required to produce a total elongation of 0.5% of a gauge length as determined by an extensometer during a tensile test.

Sphere Pig: A spherical utility pig made of rubber or urethane. The sphere may be solid or hollow, filled with air or liquid. The most common use of sphere pigs is as a batching pig.

Strain: Increase in length of a material expressed on a unit length basis (e.g., inches per inch).

Strain Hardening: An increase in hardness and strength caused by plastic deformation at a temperature below the re-crystallization range.

Stress: Tensile or compressive force per unit area in the pipe wall as a result of the loads applied to the structure.

Stress Intensity Factor: A fracture mechanics term relating the crack size, geometry, and stress acting on a crack.

Stress Raiser or Concentration: A change in contour, discontinuity, gouge, or notch that causes local increases in the stress in a pipe.

Stress Relief: Reduction of residual stresses either through a mechanical overload or through an elevated temperature.

Stress Relieving (Thermal): Heating a metal to a suitable temperature, holding at that temperature long enough to reduce residual stresses, and then cooling slowly enough to minimize the development of new residual stresses.

Swept Frequency Acoustic Interferometry (SFAI): When shear waves and longitudinal waves are superimposed onto each other they generate interference. This combination of waves creates a lamb wave, and when confined to plate surface becomes guided – hence the term 'guided wave'. Guided waves reflect back towards their origin if they encounter an inconsistency during their propagation in the medium. SFAI utilizes such guided waves at the transducer to find local anomalies in the plate (or wall of a pipe).

Sub-Critical Crack: A crack that is not large enough to cause a failure of a pipeline at a given pressure.

Survey: Measurements, inspections, or observations intended to discover and identify events or conditions that indicate a departure from normal operation of the pipeline.

Tensile Stress: Stress that elongates the material.

Tenting: A tent-shaped void formed along the longitudinal seam-weld or circumferential weld reinforcement in a pipe when the external coating is not in continuous intimate contact with the pipe and weld surfaces.

Terrain Conditions: The soil type, drainage, and topography at a given location.

Testing: See *Hydrostatic Testing (Re-Testing)*.

Tool: A generic term signifying any type of instrumented tool or pig.

Transducer: A device for converting energy from one form to another, e.g., in ultrasonic testing, conversion of electrical pulses to acoustic waves and vice versa.

Transgranular Crack: Crack growth or crack path that is through or across the grains of a metal.

Transmission Line: A pipeline, other than a gathering or distribution line, that transports gas from a gathering or storage facility to a distribution center or storage facility; operates at a hoop stress of 20% or more of the specified minimum yield stress of the pipe; or transports gas within a storage field. (See U.S. Code of Federal Regulations, Title 49, Part 192.)

Trap: Pipeline facility for launching or receiving tools and pigs.

Utility Pig: A pig that performs relatively simple mechanical functions, such as cleaning the pipeline.

Yield Pressure: The pressure at which the nominal hoop stress in the pipe wall equals the specified minimum yield stress of the pipe grade.

Yield Strength: The stress at which a material exhibits a specified deviation from the proportionality of stress to strain. The deviation is expressed in terms of strain by either the offset method (usually at a strain of 0.2%) or the total-extension-under-load method (usually at a strain of 0.5%).

APPENDIX C:
Catalogue of Available Technologies

Alternating Current Voltage Gradient (ACVG) A-Frame*

***See also Section 2.2**

Method

External Inspection Method

Description

Alternating Current Voltage Gradient (ACVG) injects an isolated low frequency (4 Hz) AC signal into the pipe while a worker measures the signal between two fixed points mounted on an A-frame as he walks along the ROW.

Strengths

The ACVG survey provides precise location of coating defects. Connects to pipeline current mappers (PCM) to capture pipe location and depth measurements. The survey does not require drilling into the ground or through asphalt as long as access to a rectifier or testing station is possible.

Weaknesses

Although capable of pin-pointing coating flaws and holidays, some disbondments may not be large enough to be detected. And its use is limited to coating flaw detection as it will not indicate areas of poor cathodic protection.

Manufacturers

Radiodetection

Utilities Using Technology

Multiple

References

http://www.radiodetection.com/
http://cath-tech.com/papers/corcopnindia2004.pdf

Magnetic Tomography

Method
External Inspection Method

Description
Transkor International makes a device that utilizes MTM to detect flaws externally by scanning for stress areas based on the disturbed magnetic domain structure that was defined at the pipe's creation.

Strengths
Capable of detecting impact flaws and corrosion by simply walking down the length of a pipeline. It requires no additional hookups or trailing wires. There is no need to take the line out of service prior to surveying.

Weaknesses
The full service surveys require an excavation after MTM scan and initial analysis. This should not be the primary defect detection method used. Additionally, it is applicable to in-service high pressure lines only, and requires a slight (10 psi) alteration in pressure to stimulate sensors to begin the survey.

Manufacturers
Transkor

Utilities Using Technology
Developed in UK, used in Malaysia and UK

References
http://www.transkor-intl.com/
http://www.transkor-intl.com/BrochureDownloads/files/MTMBrochure.pdf

Borescope

Method
External Inspection Method

Description
XLG3 VideoProbe - 3D imaging probe capable of visually determining depth, distance and size of objects or flaws in hard to reach areas with a wide variety of applications. With the accompanying software, crack depths and lengths can be recorded and analyzed for pipeline inspections.

Strengths
Directionally controllable tip. Remote viewer/controller. Internet connection. On-the-spot analysis. Variety of tip sizes. The unit is included with carrying case and field kit, and readily connects to the internet for data transfer or storage via ethernet.

Manufacturers
Measurement and Control Solutions by GE

Utilities Using Technology

Weaknesses

Despite the handheld feature, the overall unit is large and would require a field rig to protect it from harsh environments. Transporting the device would be similar to moving a home PC. It also requires a similar power supply. The unit is not designed for hazardous environments. There is no mounting mechanism to transverse the internal walls of a pipe.

N/A

References

http://www.ge-mcs.com/download/RVI/XLG3/GEIT-65043EN_xlg3ds-lo.pdf

Broadband Electromagnetic Technology

Method

External Inspection Method

Description

The external application of BEM technology induces eddy currents to flow in close proximity to a transmitter/receiver, fitted and clamped around a steel pipe. These currents migrate through the steel, allowing for a complete profile scan of the pipe to be obtained. The technique scans through coatings and debris, distinguishing and registering locations of corrosion or flaws at the scan point.

Strengths

Due to the uniquely adjustable design of the RockSolid BEM keyhole tool, pipe diameter is not a limiting factor when performing a scan. The tool has the ability to survey through thick coatings (>2") of materials such as paint, tar, plastic, and concrete commonly found on many buried and exposed pipelines. The pipeline does not have to be taken off-line, as readings are taken from the outside of the pipe. Its key-hole design facilitates spot inspection of buried or hard-to-access lengths of pipe.

Weaknesses

The detection accuracy of this unit is such that small detailed clusters of cracks may not be detected as cracks. Rather, it will indicate a wide and shallow depression of wall loss. Additionally, differentiation between ID or OD ferrous loss is not possible. This is because the data reading is based on percent-wall-loss relative to what is defined as a "good" wall (defined prior to scan). The scan range is limited to the immediate circumference below the transceivers and does not travel transversely in the pipe.

Manufacturers

RockSolid Group/GTI

Utilities Using Technology

Australia Utility

References

http://www.rocksolidgroup.com.au/admin/file/content103/c3/BEM%20brochure%20A4.pdf

Close Interval Survey (CIS)

Method

External Inspection Method

Description

A method of measuring the instant-off pipe-to-soil voltage potential along the pipeline to indicate the quality of cathodic protection provided. A surveyor walks along a pipe taking readings of the voltage potential between the pipe and the ground using two ground-level electrodes mounted on poles. A trailing copper wire is connected to the pipe at a rectifier station where a device is used to interrupt the active CP for the duration of the survey.

Strengths

CIS is the most utilized metric in any utility's integrity management program. When performed by trained personnel it can provide a detailed pipe-to-soil potential map of the pipeline indicating CP conditions and faults. Occasionally these indications can highlight areas of coating damage. A pipeline surveyed with CIS information over time can result in efficient management practices and prolonged pipeline life.

Weaknesses

CIS alone may not show areas of disbonded coating and should be a segment of a more comprehensive survey. The instrumentation may also get interference from other neighboring lines and current sources. In certain conditions drilling holes in asphalt and concrete surfaces may be required to get accurate readings, as well as wetting the surface. Requires a mechanism to synchronously disable and enable the active CP rectifier.

Manufacturers

CATH-TECH™ Hexcorder Millennium

Utilities Using Technology

Multiple

References

http://www.cath-tech.com/
http://www.corrosion-club.com/cips.htm

Direct Assessment (in excavated pipe section)

Method

External Inspection Method

Description

Direct assessment of a pipe requires exposing the pipe of interest and capturing a series of measurements about the pipe including gouge and corrosion depth gauges. Visual inspection of exposed pipelines can help identify areas of potential corrosion and indicate areas where a holiday detector may be warranted. ECDA is usually accompanied with DCVG, ACVG, and CIPS.

Strengths

Direct Assessment will validate the instruments used to identify a site for possible corrosion prior to excavation. This level of detail can reveal corrosion pits, holidays and coating flaws, or poor welds.

Weaknesses

This method is a final task in diagnosing the integrity of a pipeline. It can only detect problems on area of pipe that is exposed so locating the correct area to excavate is an issue. Cannot determine potential problems that show no external symptoms without specialized ultrasonic or X-ray scanning equipment.

Manufacturers

N/A

Utilities Using Technology

Multiple

References

ASTM G162

http://www.correng.com/PipelineIntegrity.html

External Guided Wave

Method

External Inspection Method

Description

GUL Wavemaker 4 /Teletest Focus+ use piezoelectric transducers to transmit Ultrasonic guided waves transversely, along the pipe, to locate corrosion spots, defects, and wall loss. This method must be used as a sorting or screening tool, not a measurement tool. While most commercially available versions are temporary inspection tools and moved down a pipe during a survey, GUL makes a Permanently Installed Monitoring System (PIMS) compatible with Wavemaker.

Strengths

The guided wave device completes a 100% volumetric scan of the pipe and propagates in either direction. From one location, the device scans up to a 400m length of pipe with a modest sensitivity of 5% wall loss detection. Under ideal conditions, the sensitivity reaches 1%. Pipe OD of up to 36" can be scanned. A major benefit of GUL inspection is that the line remains in service during inspection.

Weaknesses

The transducer array harness is designed for specific pipe OD. This device is not designed to be keyhole accessible, and needs exposed pipe with enough clearance for the transducer belt. Quality of the return signal depends heavily on pipe insulation and coatings. The optimal scenario requires the pipe to be bare or its coating be well bonded, to have a gaseous product, to be above grade, and to have straight lengths of pipe with no tees. Highly trained workers are required to interpret the output signals and filter through erroneous data. The device has a "dead zone" located a few inches on either side of the transducer. Longitudinal cracks are not detectable, unless the wall loss is greater than 3% and the torsional wave is used. Lastly, relative wall thickness changes are measured, as opposed to absolute wall thickness measurements.

Manufacturers

Team, Inc. (Alvin, TX)

Guided Ultrasonics LTD. (GUL)
Teletest

Utilities Using Technology

None.

References

BG Group - Pipeline Coating ILI Techniques_KK Input.docx
http://www.teletestfocus.com/teletest-focus-plus/teletest-focus-plus.jsp

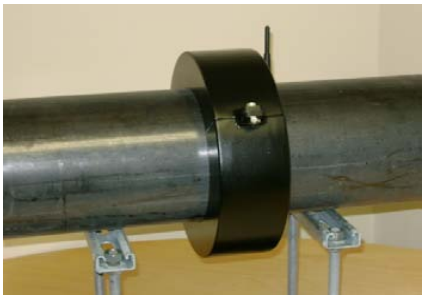
Ultrasonic Wall Thickness – Eagle Array

Method
External Inspection Method

Description
Non-invasive wireless pipeline monitoring system that incorporates a set of semi-permanent ultrasonic sensors to monitor pipeline integrity and relays the data through a cloud-based reporting system.

Strengths
The Eagle Array exhibits a number of features including wireless network connectivity, a rugged frame for extended outdoor use, and prolonged life with low power consumption. It attaches over an assets' protective coating (including FBE) requiring little-to-no surface preparation. The device is configurable for scheduled reporting and connects to a local Wifi network. There is no interruption of service during installation and has no diameter restrictions. Captured data includes temperature, humidity, moisture, vibration, surface coating, wall thickness, and corrosion rate.

Weaknesses
The unit will need to be fitted for pipe diameter. Given the harshness of some environments, antenna placement can affect connectivity quality and all connections will require IT involvement to incorporate the Eagle Array with your company's infrastructure. Will not operate on tar-coated pipe.



Manufacturers
Berkeley Springs Instruments LLC.

Utilities Using Technology
Multiple

References
http://bsisentry.com/technology/eagle-system-overview

Guided Wave

Method
External Inspection Method

Description
The Magnetostrictive Sensor Guided-Wave MsSR3030 instrument pulses a 32kHz signal into the pipe via a wire-ribbon ring attached circumferentially around an exposed segment of the pipeline. The echoed waveforms are analyzed and identified as pipeline features such as welds, pipe supports, bends or tees, and flanges. The system will also respond to pipe flaws and corrosion pits, making this a suitable method for pipeline inspection.

Strengths
The ribbon-cable sensor rings are wrapped around the pipe of interest, capable of coupling securely to any diameter pipe. The system includes a PC and accompanying analysis software to record the feedback signals. The inexpensive sensor rings induce

Manufacturers
Southwest Research Institute

Utilities Using Technology
Not widely adopted

References

transverse guided wave is much less expensive than other technologies (e.g. piezo-induced guided-wave), while still providing detailed information about the pipeline. This feature allows for the installation of a permanent sensor ring, providing year-round monitoring of pipeline assets.

http://www.swri.org/4org/d18/nde/mss.htm

Weaknesses

Although highly sensitive to anomalies in the pipe wall, the MsSR3030 cannot distinguish coating flaws from wall defects. A good coating is assumed where there is no metal loss. Additionally, asset information of the pipeline system may be helpful to distinguish standard pipeline components from sections of wall loss and corrosion. The unit does not have communication capabilities; data must be transferred manually for back office reporting.

ILI – Magnetic Flux Leakage (MFL)

Method

Internal Inspection Method

Description

The tried-and-true inspection method, Magnetic Flux Leakage, uses strong permanent magnets to induce a magnetic field axially along the pipe. This field is picked up by node transducers, where the interpretation of the field strength can indicate pipeline flaws and anomalies. A miniaturized MFL tool has been designed for distribution pipelines (shown to the left).

Manufacturers

Multiple

Utilities Using Technology

Multiple

References

British Gas Group Pipe Coating ILI Technique write-up from 2009

Strengths

MFL pigs can be used in live pipeline systems but may require pressure adjustments. The miniature model can traverse distribution lines at low pressures (up to 60 psi). The use of a delivery rod system to launch and retrieve the unit also acts as the device's movement control system. This tethers the unit for up to 1,000 feet of pipeline inspection in either direction. 4-inch pipe verified.

Weaknesses

The device must be tethered to transmit sensor data and control its movement as the line pressure is not adequate for typical ILI pressure differential propulsion. Standard MFL tools, as well as the miniature model, have the potential to lock to internal pipe wall because there is fundamentally no way of disengaging the

permanent magnets.

ILI – Spiral MFL

Method
Internal Inspection Methods

Description
Spiral MFL is an ILI tool that utilizes a helical magnetization sensor array design that eliminates the need for two orthogonal magnetizers conventionally used with TFI-MFL tools. It creates an oblique field with no inspection gaps or hidden areas, making small cracks and deformations easier to identify.

Strengths
The SMFL is effective at detecting anomalies associate with metal loss, but does so by detecting flux components in both the axial and transverse directions. This ability is capsulated in a single magnetizer module. An entirely volumetric scan can improve the classification of anomalies, and can do so in a single pass. This is a tetherless system and is propelled by pressure differential.

Weaknesses
Must be used in conjunction with standard MFL and other measurement tools for practical anomaly distinction as some readings may be ambiguous and not provide enough certainty to further investigate the flaw. Standard MFL tools, as well as the miniature model, have the potential to lock to internal pipe wall because there is fundamentally no way of disengaging the permanent magnets.

Manufacturers
T.D. Williamson

Utilities Using Technology
Multiple

References
http://www.tdwilliamson.com/ILI_Brochure/index.html

ILI – EMAT

Method
Internal Inspection Method

Description
Continuing the trend of inline pipe inspection methods, EMAT technology can provide accurate wall thickness measurements, requiring no couplant, as the unit is pressure driven down the line. The technology is very effective at detecting areas with wall loss, coating disbondments, and especially areas with stress corrosion cracking; areas that exhibit the highest risk for future corrosion or failure.

Strengths

Manufacturers
ROSEN Group

The ILI EMAT tool requires no couplant between the sensors and steel pipe making it plausible to inspect pipes with a variety of product flow and requires limited cleaning. Data captured by the device include wall loss and SCC and seam weld crack detection. Field tests have verified the functionality and application of EMAT for ILI, and NACE has recognized it as an SCC detection method. Each unit is equipped with numerous circumferential EMATs capable of providing high resolution sensing to detect flaws with a 25mm circumferential resolution.

Weaknesses

As with most ILI tools, the EMAT unit is designed for a limited number of pipeline diameters. To achieve the resolution requirements, multiple tools are strung together successively and offset from each other to form the complete system.

Utilities Using Technology

Multiple

References

http://www.roseninspection.net/MA/papers/NACE2009_ROSEN_09108.pdf

http://www.roseninspection.net/RosenInternet/InspectionServices/ILInspection/CrackCoatingDetection/

Magnetic Flux Leakage (MFL)

Method

External Inspection Method

Description

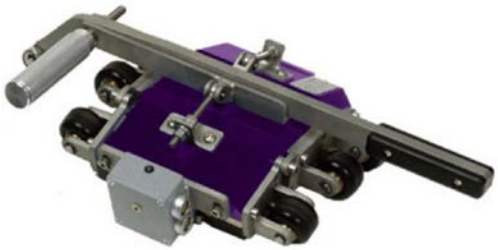
An external inspection tool called PipeScan from Silverwing puts the power of an adjustable magnetic flux leakage (MFL) pipe-screening system in the palm of your hand.

Strengths

MFL is an industry proven technology that is used commonly for wall loss and corrosion inspection. This is an external tool that can locate and measure internal metal loss. Surveys do not affect on-line product so not product flow adjustments are needed. Capable of scanning pipes or vessels up to 2.4m in diameter. A single charge will provide10-hours of scanning time.

Weaknesses

This method requires exposed pipe or vessel walls with no insulation and limited coatings. Max wall thickness to ensure accurate readings is19mm (0.75”). This unit is operated exclusively by the utility work and results are dependent on his speed and accessibility.



Manufacturers

Silverwing, UK

Utilities Using Technology

Multiple

References

http://www.silverwingndt.com/magnetic_flux_leakage/mlf_pipe_inspection/pipescan.aspx

Pipeline Pressure Test

Method

Hydrostatic Test

Description

The hydrostatic pressurization test is a method to verify the integrity and validity of a pipeline's welds, seals, connections and valves after an installation to ensure successful operation throughout the extent of its expected lifetime. The line is segmented and filled with water. The pressure of the water is increased slowly to 1.2 to 1.5 times the MAOP, depending on the code requirements. This pressure is maintained for at least 8 hours.

Strengths

Tried and true test that aids in detection and locating of pipe flaws, bad welds, valves, or joints. Running a test at a significant margin of pressure over the MAOP ensures a high quality pipeline capable of withstanding unusual and harsh treatment. Water is a clean and inert fluid that poses little risk to the surrounding environment.

Weaknesses

A hydrostatic test requires significant amount of water to be hauled to the entry location. The introduction of water to the pipeline is not considered ideal, as water that is not thoroughly removed will cause corrosion. It is necessary to shut down the pipeline to perform the test, which can be difficult depending on the location of the line in the system.

Manufacturers

N/A

Utilities Using Technology

Multiple

References

ASTM G162

http://www.pge.com/myhome/edusafety/systemworks/gas/pipelinesafety/hydrostatictesting/

Pipeline Integrity Tester

Method

Hydrostatic Tests

Description

The PIT5000 is a real-time digital data acquisition system for hydrostatic testing of pipelines. Provides a means to automate the entire pressurization process and records critical parameters to verify pipeline integrity in real-time.

Strengths

Software program monitors and plots pressure, ambient temperature, and pipe temperature in real-time using a NIST traceable DAQ system. The PIT5000 also provides site data entry, data logging, pump stroke counter, and limits with associated visual alarms. The software includes a tolerance alert system that meets Part 192 subpart J and Part 195 subpart E IMP requirements. Roller case makes field locations more accessible.

Weaknesses

Total weight of the unit is 100-lbs and is not a portable device. This is a

Manufacturers

Meriam Process Technologies

Utilities Using Technology

sold as service

standalone system with no connectivity options for off-site data storage or GIS integration. Data can be extracted manually. Does not include GPS location information.

References

http://www.labcell.com/media/37254/pit5000%20data%20sheet%20r4.pdf

ILI – Locomotive RFEC

Method

Internal Inspection Method

Description

The Explorer-II with Remote Field Eddy Current (RFEC) transducers is an inline inspection tool for steel pipelines. This locomotive driven pig performs circumferential wall thickness scans while it transverses at a controlled rate. The transducers are housed on an expandable ring located on one of the center modules. Other modules provide locomotion, visual feedback sensors, power, and computing operations. The unit is fully controllable by a remote user with real-time feeds of all sensors and actuators.

Strengths

The Explorer-II can be launched into an active pipeline pressurized up to 750 psi using an industry standard hot-tap. Once deployed, the unit transmits data commands using a tetherless/wireless communication channel. This provides the operators with a real-time data stream and video feed. The fully encapsulated and modular design ensures resistance to harsh elements and complex pipe systems. In 2011 the device became commercially available for 6-26 inch pipe.

Weaknesses

Any robotic system runs a risk of malfunction when transporting, controlling, and powering the many components that make up its system. The scanning modules may stick to the wall due to the intense magnets and impact may damage the delicate sensors attached to the modules. Removing a malfunctioning robot is far more difficult than removing a pressure-driven pig.

Manufacturers

PipeTel Technologies.

Utilities Using Technology

Various North American Utilities including SoCal Gas

References

http://www.pipetelone.com/

ILI – MFL and TFI

Method

Internal Inspection Methods

Description

Weatherford offers an array of pigging equipment utilizing UT, MFL, and TFI. In the case of MFL/TFI, strong permanent magnets are used to induce a magnetic field axially along the pipe. Node transducers will interpret loss of field strength, indicating a flaw. All products and inspection services are commercially available.

Strengths

Warranted by MFL's verified success and industry adoption, typical inspections include a full packaged service, accompanied with proprietary analysis and data organization tools. MFL scans, along with other ILI tools, report detailed wall-loss and crack detection information circumferentially for the entire length of pipe.

Weaknesses

Modules are limited to specific diameter pipe and are primarily used on transmission pipelines. Line must be purged of product, cleaned, and taken out of service before use.

Manufacturers

Weatherford

Utilities Using Technology

Multiple

References

http://www.weatherford.com/Products/Production/PipelineSpecialtyServices/InspectionMFLTFI

Section 2.2: Long-Term Condition Monitoring Techniques

DCVG*

***See also Section 2.1**

Method

Corrosion Surveys

Description

Current Voltage Gradient Survey (DCVG) is a common component of external pipeline inspection commonly accompanied with ACVG surveys and CIPS. DC current is injected into the pipe and switched on and off periodically (<1Hz) by means of an interrupter. A utility technician walks along the ROW, measuring the current absorbed by two handheld copper-copper sulfate reference electrodes mounted on poles. The difference in current, calculated by a specially designed voltmeter, indicates the location of possible current leaks, signifying a flaw in the pipe's coating.

Manufacturers

CATH-TECH™ Hexcorder Millennium

Utilities Using Technology

Multiple

References

Strengths

A DCVG survey accurately locates areas where a pipe's coating

may be deteriorating. The current gradient can indicate the severity of the damaged area, allowing a skilled field technician to prioritize repair excavations accordingly. Does not require a trailing wire during survey.

Weaknesses

Due to its reliance on the principle of ground conductivity, this technique is not useful on bare pipes. Also, in complex systems, interference from other line's CP may impact the DCVG's readings. In some environments, such as asphalt and concrete surfaces, access holes may be required to ensure sufficient current flow.

ASTM B826 http://www.cath-tech.com/

http://www.corrosion-club.com/dcvg.htm

ACVG*

See also Section 2.1

Method

Corrosion Surveys

Description

Alternating Current Voltage Gradient (ACVG) injects an isolated low frequency (4 Hz) AC signal into the pipe while a worker measures the signal between two fixed points mounted on an A-frame as he walks along the ROW.

Strengths

The ACVG survey provides precise location of coating defects. Connects to pipeline current mappers (PCM) to capture pipe location and depth measurements. The survey does not require drilling into the ground or through asphalt as long as access to a rectifier or testing station is possible.

Weaknesses

Although capable of pin-pointing coating flaws and holidays, some disbondments may not be large enough to be detected. And its use is limited to coating flaw detection as it will not indicate areas of poor cathodic protection.

Manufacturers

Radiodetection

Utilities Using Technology

Multiple

References

http://www.radiodetection.com/
http://cath-tech.com/papers/corcopnindia2004.pdf

ER Sensors

Method

Corrosion Monitoring

Description

The Electrical Resistance Field Sensors - MS1500E Corrosion Data Logger is a field-ready analysis tool capable of reading and storing data from a variety of resistance measuring probes. The device will calculate metal loss in mils and corrosion rate in mils per year (mpy) based on the behavior of resistance.

Strengths

ER sensor packs are battery powered and portable; ready for use in the field with an easy to use interface. On-board storage can hold up to 3,100 sensor readings and later be downloaded to a PC for further analysis. Measurements may be taken in harsh or dangerous environments due to its intrinsically safe certification. Interchangeable probes include: Wire Loop, Tube Loop, Cylindrical, Flush, Strip, depending on application.

Weaknesses

Readings must be taken by a trained professional as time and placement play significantly in the accuracy of corrosion readings. Communication is limited to transferring stored data to a PC.

Manufacturers

Metal Samples, Inc.

Utilities Using Technology

ConEd of NY, SWGas, Questar

References

ASTM B826

http://www.alspi.com/ms1500e.pdf

Remote DAQ System

Method

Remote CP Monitoring

Description

A remote pipeline monitoring system capable of capturing critical CP and pipeline characteristics, and serving them up to a cloud-based portal for remote access. Units are capable of monitoring CP parameters that would normally be captured manually by utility personnel. The housing boxes can be mounted at CP test stations as shown or at rectifier stations where additional data can be captured.

Strengths

These devices are capable of monitoring AC potential, DC potential, DC instant-off potential, DC corrosion current, AC current density and DC native potential. All these parameters can assist utilities mitigate AC interference on their pipelines and prevent corrosion. Data plots and raw periodic data can be downloaded from Elecsys' online portal interface which allows access to every sensor box in your system. User configurable options allow for custom systems and setups. Custom alerts can also be set in when values exceed limits. Each box has a cellular or satellite communication module providing a secure and encrypted connection.

Weaknesses

This technology is still in its incipient stage as there are significant hurdles to manage with such a complex, remote, embedded system. Communication reliability is factor that can inhibit configuration uploads or data downloads. High voltage or over current protection circuitry is integrated but not all situations can be accounted for.

Manufacturers

Elecsys Corporation (US). Abriox (UK).

Utilities Using Technology

UK-based Wales & West Utilities

References

http://www.elecsyscorp.com/wireless-remote-monitoring/
http://www.abriox.com/

LPR Sensor

Method

Corrosion Monitoring

Description

The Aquamate CORRATER® Liner Polarization Resistance (LPR) sensor is a portable corrosion rate instrument. With an applicable probe attached, the device can produce the corrosion rate in mils per year (MPY), the imbalance reading, conductivity, and the water temperature. Although designed for use in water systems, its application extends to analyze pipeline conditions and better prepare for pipeline maintenance.

Strengths

The unit is battery operated, handheld, and portable. Only requires a few minutes to take accurate readings. Measures corrosion rate, imbalance readings, conductivity, and temperature. Can be used with any water based (i.e. soil).

Weaknesses

Typically a permanent installation of the sensor probe into a water line. The pictured probe is better suited for soil conductivity measurements

Manufacturers

Rohrback Cosasco Systems

Utilities Using Technology

Water utilities

References

ASTM G59

http://www.cosasco.com/lpr-corrosion-instrument.html#products

Gas Chromatography

Method

Product Quality Control

Description

A field ready, stand-alone gas chromatograph can monitor the pipeline's contents for quality management practices and provide real-time alerts when issues arise. This technology may serve well at ownership hand-off stations or process plants. Emerson and Siemens are top manufacturers of such field devices.

Strengths

SCADA integration and remote access software allow for system configuration uploads and real-time data downloads. Its rugged field-ready design requires no shelters and can be mounted and connected in existing substations. The condensed and ruggedized technology is capable of gas level detection with parts-per-billion (ppb) accuracy.

Weaknesses

These devices can be installed anywhere along the ROW, but it requires access to an external power source and a communication connection to a SCADA system.

Manufacturers

Daniel (Emerson) Danalyzer ®.
Siemens Sitrans CV.

Utilities Using Technology

Multiple

References

http://www2.emersonprocess.com/en-US/brands/daniel/gc/Pages/GC.aspx

Steel Coupons

Method

Corrosion Monitoring

Description

A coupon is a piece of steel with a specified exposed surface area that is buried next to a pipe. The coupon is attached to a wire brought up to a CP test station box and then connected to another wire, cad-welded to the actual buried pipe. This polarizes the coupon to a very similar potential as the pipe. Usually buried with a reference electrode. The coupon is used for regular periodic inspection of CP levels to maintain proper integrity management of the pipeline. Early signs of corrosion can be detected with this methodology.

Strengths

Coupons serve as a long-term corrosion control indicator. They are inexpensive and are permanently buried. They eliminate issues associate with measuring pipe-to-soil potential on pipes with multiple active CP rectifiers or permanently attached CP anodes. Further design advancements have made coupons a reliable and low-error method for capturing the instant-off potential of protected pipelines.

Weaknesses

Coupon testing is not widely automated and requires field technicians to manually take readings.

Manufacturers

MC Miller Co., Electrochemical Devices Inc., Farwest Corrosion (distributor)

Utilities Using Technology

Multiple

References

NACE RP0502

http://www.edi-cp.com/pdf/05039.pdf

Section 2.3: Risk Modeling and Incident Prediction Tools. Software Applications/SCADA

Digital Signal Analysis*

***See also Section 2.5**

Method

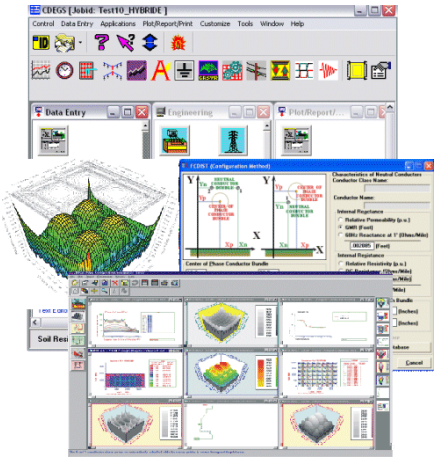
Digital Signal Analysis

Description

The response of the pressure, flow, and other sensors to a known impulse change in flow is measured and digital signal processing on these normal operation responses is used to recognize the changes in the responses of these sensors when a leak or other event occurs.

Strengths

Able to detect 1% leaks in seconds to minutes. Leaks can be



detected for shut-in and transient conditions. False alarms are less frequent. Leak location can be estimated. Maintenance is easy.

Weaknesses

Existing leaks and leaks in slack line conditions cannot be detected. Leak volume difficult to estimate. Implementation and testing are difficult. Costs are high.

Manufacturers

GL Noble Denton, Safe Engineering Services, Inc.

Utilities Using Technology

Multiple

References

PHMSA Leak Detection Technology Study for PIPES Act (H.R. 5782)

Use of Real-Time Transient Model Software*

See also Section 2.5

Method

Real-Time Transient Model

Description

The model simulates transient flows in the pipeline. The application software generates a real-time transient hydraulic model using field input from meters at strategic receipt and delivery locations, referred to as software boundary conditions. Fluid dynamic characteristic values are modeled throughout the pipeline, even during system transients. The RTTM software compares the measured data for a segment of pipeline with its corresponding predicted values.

Strengths

Able to detect 1% leaks in seconds. Leak flow rate and leak location can be estimated. Leaks can be detected for shut-in, slack line, and transient conditions.

Weaknesses

The method is difficult to learn and use. The model must be customized and tuned to each unique pipeline configuration. Implementation, testing, and maintenance are difficult. Costs are very high.

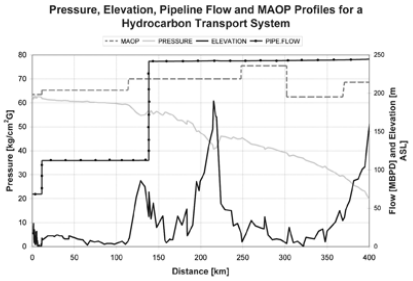


Figure 4. Pipeline profile for Pressure and Flow Evaluation as a Function of Elevation and Distance from Pump.

Manufacturers

Stoner SPS/Leakfinder, Simulations Inc. - LEAKWARN, LICEnergy Inc - Pipeline Leak Detection System

Utilities Using Technology

Multiple

References

PHMSA Leak Detection Technology Study for PIPES Act (H.R. 5782)
http://www.gasmachineryjournal.com/EffectivePipelineSim

Statistical Analysis*

***See also Section 2.5**

Method

Statistical Analysis

Description

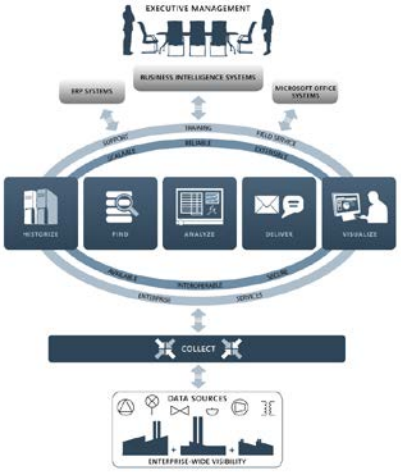
Statistical analysis is performed on a measured pressure to discern a decrease in the mean value over a threshold. To reduce the frequency of false alarms, more sophisticated statistical analysis methods use pressure and/or flow at multiple locations. Leak alarm generation is based on a set of consistent patterns of relative changes of the mean data at different locations.

Strengths

Able to detect 1% leaks in seconds to minutes. Leaks can be detected for shut-in and transient conditions. False alarms are less frequent. Leak location can be estimated. The method is easy to use. Retrofitting and maintenance are easy. The method is more robust.

Weaknesses

Existing leaks and leaks in slack line conditions cannot be detected. Leak volume difficult to estimate. Implementation and testing are difficult. Costs are high.



Utilities Using Technology

Multiple

References

PHMSA Leak Detection Technology Study for PIPES Act (H.R. 5782)

Current Mapping

Method

Pipe Locating

Description

Pipeline Current Mapper Plus (PCM+). Often included in regulatory pipeline inspections and based on a similar concept of the DCVG survey, the PCM+ provides a means to locate underground utilities and observe the current gradient of the pipeline, as well as detect disbondments and areas of failed coatings where CP currents are leaking into the soil. The device requires access to the pipe but allows a utility work to inspect up to 30 km (19 miles) of pipeline.

Strengths

One connection at a CP test station or rectifier energizes 30km of pipeline capable of current mapping, thus stream-lining the inspection process. Automatic mapping software in the handheld unit is capable of storing 1,000 data points and GPS coordinates. Direct connect "current spans" are no longer necessary. Data points can be linked to a PDA over a wireless Bluetooth connection.

Weaknesses

A PCM+ survey requires relative knowledge of pipeline location and asset information. Similar pit-falls as ACVG, for example coatings are assumed to be pristine at locations with no current leakage is indicated. Access to a CP test station or rectifier is necessary to empress the locating signal onto the pipeline.

Manufacturers

Radiodetection

Utilities Using Technology

Multiple

References

http://www.radiodetection.com/

Ground Penetrating Radar (GPR)

Method

Pipe Locating

Description

Uses a radar device to detect underground utilities.

Strengths

Ability to detect both subsurface utilities, metallic and plastic. GPR is frequently used to detect utilities or obstructions that may not have been shown on plans or located by other traditional methods.

Weaknesses

Limited ability to determine the exact composition of the utility (e.g., steel, plastic, cast iron). Can only detect location/depth. Cannot provide specific characteristics of the utility. Soil type and water content can sometime result in poor readings. The use of GPR is expensive relative to some other traditional locating technologies.

Manufacturers

Multiple

Utilities Using Technology

Multiple

References

http://www.geophysical.com/

Injected Acoustic

Method

Pipe Locating

Description

MADE-SA Gas Tracker is a PE pipe locating system, based on the propagation of an injected acoustic signal and the detection of the signal by a utility worker walking along the anticipated ROW, using a specially designed signal locating device.

Strengths

The technology locates plastic pipe. A transmitter connects to an inlet U tube that is easily connectable to a distribution line. The system is portable and the attached U tube can remain a useful access point for future tests. The receiver is hand-held and is reliable in high acoustic noise environments.

Weaknesses

Cost for the service is $16,500 USD. Product must be taken off line to begin locating. Range is undefined as the manual states "several blocks" of pipe can be located.

Manufacturers

MADE-SA

Utilities Using Technology

Service originated in France and used throughout Europe

References

http://www.made-sa.com/ftp/pgiArticle/GAS_TRACKER_US/GU_GAS_TRACKER_V_3_10_EN.pdf

LIDAR

Method

Airborne Platforms

Description

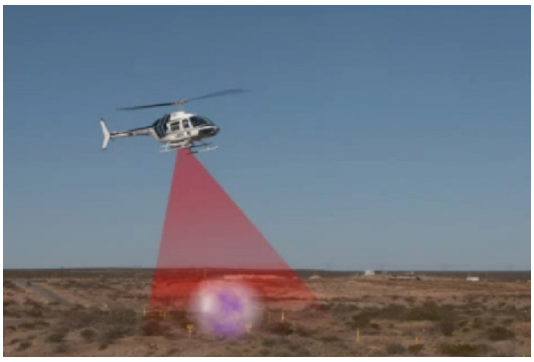
Fly-by pipeline leak detection using infrared laser differentiation to scan the area below the flight path and pinpoint natural gas plumes from hundreds of feet away.

Strengths

This method is faster, safer, than conventional walked/driven surveys and minimizes probability of missing a leak indicator. Photographs are taken of area being scanned to better identify leak location. The device allows for pipelines in harsh, overgrown, or impassible environments to be scanned for leaks without endangering utility personnel.

Weaknesses

The technology has been developed and used in flight pipeline surveillance since 2006. Relatively expensive to operate an aircraft.



Manufacturers

LASEN, ITT (ESRI)

Utilities Using Technology

Interviewed utilities have expressed interest. No testimonials found.

References

http://www.laseninc.com/

PipeGuard

Method

Vibration Detection

Description

A subsurface detection tool used to sense vibrations in the soil to provide notification of any potential encroachment in the area.

Strengths

Can provide continuous monitoring for subsurface disturbances. Easy to install. Tamper-proof. Buried underground.

Weaknesses

Runs on lithium battery that will need to be maintained/replaced. Potential for false alarms.

Manufacturers

Magal S3

References

http://www.magal-s3.com/contentManagment/uploadedFiles/SolutionsProducts/PipeGuard_Magal_Eng.pdf

One-Call Centers

Method

Pipe Locating

Description

A "one-call" center is a service provider that utilizes various pipe locating tools to identify and mark the locations of buried assets before any permanent structure is added or altered in an area. These include mail posts, fences, trees, decks,

Strengths

Identifying these critical underground obstacles can make or break a weekend project, construction of a building, or an HDD pipe installation. Having a clear and labeled indicator will improve the success rate of an installation and reduce possibility of third-party damage.

Weaknesses

Requires a skilled technician to travel to the location and manually mark the locations. Potential for mis-marking/mis-identification as the markings can be moved, tampered with, removed, or dug up and lost.

Manufacturers

Julie (Illinois), Call811, DigAlert

Utilities Using Technology

Multiple

References

ASCE 32-02

Magnetic Locating

Method

Pipe Asset Locating

Description

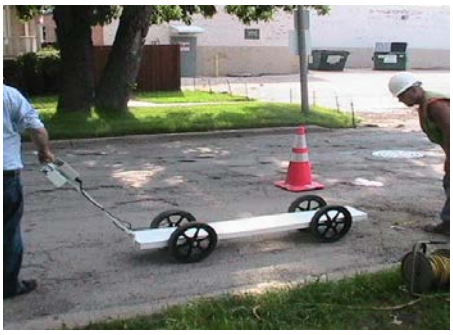
Metallic Joint Locator (MJL) will locate cast iron or steel pipe joints based on magnetic field induction. It injects a magnetic field into the pipe and detects the location of an increase of magnetic induction, resulting in the location of a joint. This technology was commercialized in 2010 and is used in SensIT Technologies' ULTRA-TRAC® MJL.

Strengths

The successfully field-proven technology locates cast iron joints at depths of 1m below grade. This is a GTI technology that has recently been licensed for manufacture.

Weaknesses

The commercialized product has a maximum reading depth of 1m. Urban areas will require traffic control and lane closures.



Manufacturers

SensIT Technologies

Utilities Using Technology

N/A from interview, SensIT is located in Indiana

References

http://www.gasleaksensors.com/products/ultra_trac_mjl.html

Time Domain Reflectometry

Method

Transmission Signal Condition (Fiber Optic)

Description

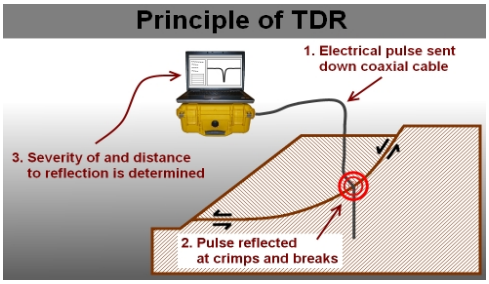
Fiber Optic Intrusion Detection. A length of fiber optic cable is buried along the ROW and connected to an alert system. If the system detects a disturbance along the cable length, an alert will inform a one-call center with the approximate location of the incident. Technology can also be used with coaxial cable.

Strengths

Long-range encroachment and intrusion monitoring. Capable of using industry standard MODBUS and TCP/IP connectivity for SCADA integration. Can located an intrusion or break within 150m. Monitoring range covers up to 25 miles per base station.

Weaknesses

No immediate deterrent for crew causing the damage. Requires a substantial attack on the fiber cable. Cable design requires replacement after intrusion detection or break in line.



Manufacturers

Future Fibre Technologies Security, EDM Services TripWire

Utilities Using Technology

N/A

References

http://www.kanegeotech.com/TDR.html

Video Detection

Method

Security Camera

Description

Using video detection cameras and software to identify encroachments in right-of-way to notify operators of any unauthorized presence. The AVT234 is designed for military use and reconnaissance complete with auto-tracking, infrared cameras that alert a remote command center of intrusion.

Strengths

Automatically monitors the ROW without the need for personnel intervention. Fully automated system requiring no calibration. The system can be permanently installed or used for temporary digging sites. Incorporates up to four cameras to eliminate blind spots. Any brand camera can be used so setup can be customized per application. 3G-cellular communication capabilities.

Weaknesses

Will only monitor what is in the camera view, so many cameras and base stations are necessary to cover a large area such as a pipeline installation site. Proper placement of the units is critical to the success of the system, possibly not identifying any risks at all.

Manufacturers

Axial Technologies

Utilities Using Technology

N/A

References

http://www.prweb.com/releases/2011/7/prweb8626498.htm
http://www.axial-tech.com/reconisensetrailersellsheet.pdf

Airplane/Helicopter Visual Survey

Method

Airborne Platforms

Description

Flying over the pipeline ROW to visually inspect and identify any encroachments on the ROW. Identification of leaks can be made by observing areas of vegetation that appear brown while others are green.

Strengths

This method surveys large areas quickly and easily identifies areas of encroachment and large leaks that affect vegetation. Also helpful to identify areas of concern for planning excavations such as buildings and nearby HCA's. Documentation of identified leaks can be recorded with GPS coordinates and trip routes.

Weaknesses

Low flying vehicles have certain risks associated with them requiring trained personnel to maintain the aircraft and define a flight plan and get it approved for the intended route. Visual inspection may not be adequate to identify minor leaks or areas of corrosion, requiring further investigation.

Manufacturers

Multiple

Utilities Using Technology

Multiple

References

http://www.laseninc.com/

Digital Signal Analysis

Method
Digital Signal Analysis

Description
The response of the pressure, flow, and other sensors to a known impulse change in flow is measured and digital signal processing on these normal operation responses is used to recognize the changes in the responses of these sensors when a leak occurs.

Strengths
Able to detect 1% leaks in seconds to minutes. Leaks can be detected for shut-in and transient conditions. False alarms are less frequent. Leak location can be estimated. Maintenance is easy.

Weaknesses
Leaks in slack line conditions cannot be detected. Leaks that exist when the baseline measurements are taken are undetectable. The method only can detect changes from the baseline. Leak volume difficult to estimate. Implementation and testing are difficult and costs can be high.

Manufacturers
Multiple

Utilities Using Technology
Multiple

References
PHMSA Leak Detection Technology Study for PIPES Act (H.R. 5782)

Flame Ionization Detectors (FID)

Method

Hand-Held Technologies

Description

Detects the presence of volatile organic compounds (VOCs) that indicate the level of methane gas in the area. This model is portable and applicable for buried pipeline leak detection, HAZMAT areas, leak detection and repair (LDAR), etc.

Strengths

This device is designed to be portable with its user-friendly interface, self-contained power source, and walking handle. It has a wide VOC range meaning it can detect a variety of potentially harmful gases. It can store surveyed data and is enabled for Bluetooth connectivity, providing means of data transfer. The unit meets industry standard intrinsic safety requirements. A 70-hour fuel cell provides the necessary resources to handle any surveying job.

Weaknesses

Gas detection is limited to VOC's, excluding sulfur and other highly toxic gases commonly found in processing plants or refineries.

Manufacturers

PhotoVAC

Utilities Using Technology

Multiple

References

http://www.photovac.com/hand-held-flame-ionization-detector.aspx

Helicopter-Mounted Laser Leak Detection

Method

Laser-Based Technology

Description

A tool that samples the air above the pipeline and uses specially designed laser technology to detect methane. The tool is attached to a sampling chamber mounted on the base of a helicopter. As it flies above the pipeline ROW, the unit samples the air 300 times a second for traces of methane with part-per-million accuracy (ppm).

Strengths

The laser sensor can detect methane with an accuracy of 1 part-per-million. Real-time detection is indicated during flight and alert areas can be coupled with a GPS unit to accurately record leak indications.

Weaknesses

An aerial scan can only provide an approximate location of the

Manufacturers

Vertex Helicopters

Utilities Using Technology

Interest expressed by all Interview utilities

References

http://www.vertexhelicopters.com/ald

identified leak. Even with extrapolation, pinpointing the location on the ground is difficult. Cost of trained flight personnel, aircraft maintenance and flight plans must be considered before using this leak detection method.

.html

Metering

Method

Volume Balance

Description

Measurement of the difference in incoming versus outgoing delivery volumes. Utilities know the volume of gas that they purchase from their source, and compare that to the volume of gas that is sold at their own meters.

Strengths

This method is relatively easy to use. Testing and maintenance is relatively easy. Costs are relatively low. This method can detect a less than 5% leak in minutes to hours.

Weaknesses

Leaks cannot be detected in shut-in or slack line conditions. In other words, if no gas is flowing through the meters, you will not be able to detect a leak using this method. Small leaks may have long detection times. The precise location of leak cannot be determined using this method.

Manufacturers

Multiple

Utilities Using Technology

Multiple

References

PHMSA Leak Detection Technology Study for PIPES Act (H.R. 5782)

Optical-Based Technologies

Method

Remote Leak Survey

Description

Point or open-path monitoring of combustible gases using IR (infrared) gas detectors or catalytic bead detectors.

Strengths

IR detectors are more accurate and require less calibration than catalytic bead-based detectors. They do not require the presence of oxygen. An open-path detector can increase the sampled gas to accommodate large flow areas or storage containers.

Weaknesses

The devices can be expensive. They can only detect hydrocarbon, or other IR-absorbing compounds. Limited operating temperatures and humidity.

Manufacturers

General Monitors, Multiple others

Utilities Using Technology

Multiple

References

http://www.generalmonitors.com/downloads/white_papers/IR_VS_CATALYTIC.PDF

Pressure/Flow Monitor

Method

Rate of Pressure/Flow Change

Description

Rapid depressurization, rapid inflow increase, rapid outflow decrease, and rapid increase in the difference between inflow and outflow are associated with the onset of a leak.

Strengths

Leaks can be detected in shut-in conditions. Can estimate the volume and location of large leaks. Retrofitting and maintenance are easy. Able to detect 5% leak in minutes.

Weaknesses

Small leaks, existing leaks, and leaks during slack line conditions cannot be detected. Implementation and testing are not easy. The method is not easy to learn and use. False alarms are frequent during transient conditions. Method is less robust than others.

Manufacturers

Multiple

Utilities Using Technology

Multiple

References

PHMSA Leak Detection Technology Study for PIPES Act (H.R. 5782)

Mass Balance with Line Pack Compensation

Method

Mass Balance with Line Pack Compensation

Description

This is a data analysis method used to determine if there is a leak in the system. In this method, leak flow equals inlet flow minus the outlet flow minus the rate of change in line pack. When the leak flow exceeds a specified threshold, a warning is displayed and an alarm sounds. Volume imbalance is typically monitored over a number of time periods to detect commodity releases of different sizes.

Strengths

Existing leaks and leaks for shut-in and transient conditions can be detected. Able to detect 1% leaks in minutes. Leak detection can be used during transient conditions with less frequent false alarms. The method is adaptable to any pipeline configuration.

Weaknesses

Leaks cannot be detected during slack line conditions. Implementation, retrofitting, and maintenance are not easy. The location of a leak cannot be determined. High cost.

Utilities Using Technology

Multiple

References

PHMSA Leak Detection Technology Study for PIPES Act (H.R. 5782)

Use of RTTM Software*

See also Section 2.3

Method

Real-Time Transient Model

Description

The model simulates transient flows in the pipeline. The application software generates a real-time transient hydraulic model using field input from meters at strategic receipt and delivery locations, referred to as software boundary conditions. Fluid dynamic characteristic values are modeled throughout the pipeline, even during system transients. The RTTM software compares the measured data for a segment of pipeline with its corresponding predicted values.

Strengths

Able to detect 1% leaks in seconds. Leak flow rate and leak location can be estimated. Leaks can be detected for shut-in, slack line, and

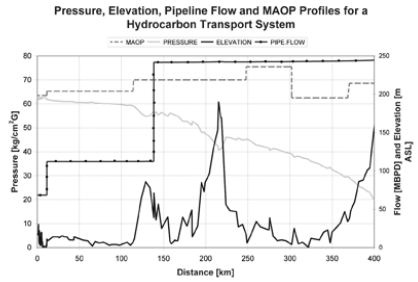


Figure 4. Pipeline profile for Pressure and Flow Evaluation as a Function of Elevation and Distance from Pump.

Manufacturers

Stoner SPS/Leakfinder, Simulations Inc. - LEAKWARN, LICEnergy Inc - Pipeline Leak Detection System, Osisoft PI

transient conditions.

Weaknesses

The method is difficult to learn and use. The model must be customized and tuned to each unique pipeline configuration. Implementation, testing, and maintenance are difficult. Costs are very high.

Utilities Using Technology

Multiple California utilities

References

PHMSA Leak Detection Technology Study for PIPES Act (H.R. 5782)

Statistical Analysis*

See also Section 2.3

Method

Statistical Analysis

Description

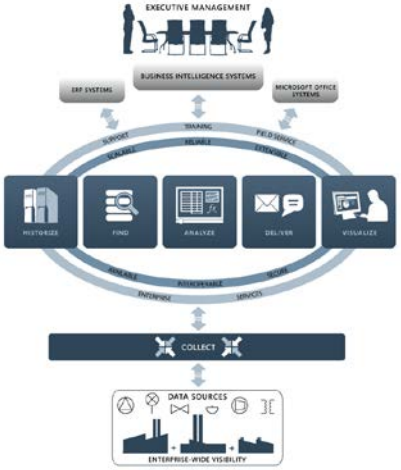
Statistical analysis is performed on a measured pressure to discern a decrease in the mean value over a threshold. To reduce the frequency of false alarms, more sophisticated statistical analysis methods use pressure and/or flow at multiple locations. Leak alarm generation is based on a set of consistent patterns of relative changes of the mean data at different locations.

Strengths

Able to detect 1% leaks in seconds to minutes. Leaks can be detected for shut-in and transient conditions. False alarms are less frequent. Leak location can be estimated. The method is easy to use. Retrofitting and maintenance are easy. The method is more robust.

Weaknesses

Existing leaks and leaks in slack line conditions cannot be detected. Leak volume difficult to estimate. Implementation and testing are difficult. Costs are high.



Manufacturers

Osisoft PI system

Utilities Using Technology

Multiple

References

PHMSA Leak Detection Technology Study for PIPES Act (H.R. 5782)

Wavelength-Scanned Cavity Ringdown Spectroscopy (WS-CRDS)

Method

Laser-Based Technology

Description

Picarro G1301 is a real-time (10hz) ambient gas analyzer that can monitor precise (ppbv) amounts of CO2/CH4 and (ppmv) H20 in the locally sampled air. Calibration is completed at the factory and requires no adjustments or maintenance

Strengths

This technology has been integrated into a field-ready unit capable of rapid air quality profiling and chemical detection on high speed vehicles. The fast sampling and detection rate, joined with a high resolution, low calibration-drift technology (WS-CRDS) allows for quick detection of leaks in harsh environments where other technologies or manual walk-through sampling would be unreasonable.

Weaknesses

This technology comes at a high price tag and requires significant preparation for field use or adapting it to the vehicle of choice. A connected PC is required for operation, and thus a substantial power source is also needed. Detectable gas types are defined for each unit and not adjustable.

Manufacturers

Picarro. Isometric Instruments makes a similar device called GYRO.

Utilities Using Technology

Interviewed utilities express interest

References

http://www.picarro.com/gas_analyzers/flight_co2_ch4_h2o

LIDAR*

*Also see section 2.4 *Right-of-Way Encroachment and Excavation Damage Prevention*

Method

Laser-Based Technology

Description

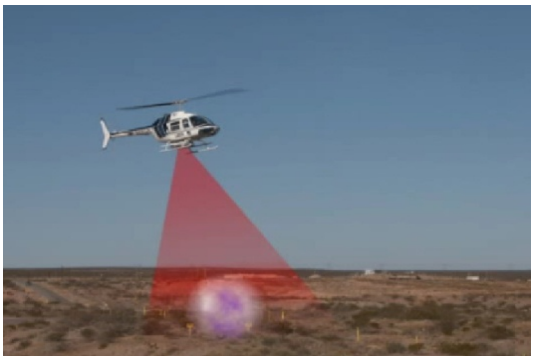
Fly-by pipeline leak detection using infrared laser differentiation to scan the area below the flight path and pinpoint natural gas plumes from hundreds of feet away.

Strengths

This method is faster, safer, and more accurate than conventional walked/driven surveys and minimizes probability of missing a leak indicator. Photographs are taken of area being scanned to better identify leak location. The device allows for pipelines in harsh, overgrown, or impassible environments to be scanned for leaks without endangering utility personnel.

Weaknesses

The technology has been developed and used in flight pipeline surveillance since 2006.



Manufacturers

LASEN, ITT (ESRI)

Utilities Using Technology

Interviewed utilities have expressed interest. No testimonials found.

References

http://www.laseninc.com/

Section 2.6: Remote Stress/Strain Analysis of Pipeline

Ring Expansion Testing

Method

Ring Expansion Testing

Description

Ring Expansion Testing is a cost effective way to verify and test steel pipe manufacture's specifications and certified ratings of pipe purchased by utilities and used in transmission pipelines. The Specific Minimum Yield Strength is being testing on a 76mm ring cut from the pipeline, shown to the right.

Strengths

Measures SMYS and failure conditions of a section of pipeline to verify the remaining portion of the pipe meets requirements. This testing also measures wall thickness of a section of pipe. Can be used to determine failure rates of samples with identified defects to better prioritize pipeline maintenance. Only requires a small segment of pipe to be removed from the pipeline.

Manufacturers

GL Noble Denton

Utilities Using Technology

California utilities

Weaknesses

Does not test entire length of pipe (only small section) and requires isolating product flow to remove the segment. The testing conditions may not include all conceivable field situations.

References

http://www.pipelineandgasjournal.com/fixing-america%E2%80%99s-pipeline-system-ring-expansion-testing

Fiber Optic

Method

Fiber Optic Strain Monitoring

Description

A fiber optic cable is adhered to the outside of a pipeline for the length of the pipe. The fiber has the ability to sense areas of strain and measure temperature of the pipeline and communicate that back to a DAQ center. Usually installed on a newly installed segment of pipe to monitor its settling characteristics.

Strengths

High accuracy and sensitivity to pipe strain. Once installed, relatively easy to maintain. Provides real-time strain monitoring and can alert the utility or monitoring service when conditions worsen. It can be particularly useful in areas with high seismic activity.

Weaknesses

Difficult to install on existing pipelines and will only detect stain changes from the time it was installed. Requires a specifically designed fiber optic communication system.

Manufacturers

Multiple

Utilities Using Technology

Italian utility, multiple USA utilities

References

http://www.roctest-group.com/~rtgroup/sites/default/files/bibliography/pdf/c126.pdf

Strain Gauge

Method

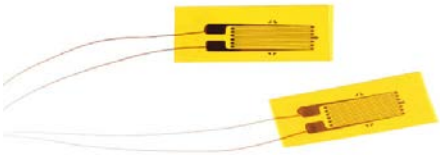
Strain Gauge

Description

A device that monitors changes in strain due to bending/movement of the pipe. The device uses a pattern of wire to translate the movement into a measureable electrical signal.

Strengths

Can detect variations in pipeline strain. Provides important information with regard to seismic activity and land movement.



Manufacturers

Multiple

Weaknesses

Only provides information at location where installed. Short life span. Difficult to maintain.

Utilities Using Technology

Multiple

References

http://www.omega.com/literature/transactions/volume3/strain.html

FRASTA – Fracture Surface Topography Analysis

Method

FRASTA. Scanning Electron Microscope (SEM) with stereograph capabilities.

Description

FRASTA, or Fracture Surface Topography Analysis, uses SEM to examine the surface topography of a crack in order to reconstruct the cause and determine effects of pressurization.

Strengths

This method can help determine the cause of a crack. The use of the data can help determine the life expectancy of the pipeline and set appropriate inspection intervals.

Weaknesses

Will not identify where cracks are. It is a post-crack analysis method, meaning it will not help to prevent them. It will only help determine why it formed and how it quickly it may grow or propagate.

Manufacturers

SRI International

Quantitative Polymerase Chain Reaction

Method

Biological and genetic microbial influenced corrosion (MIC) testing services

Description

A PCR process that surpasses shortcomings of conventional methods by targeting the specific corrosion causing bacteria and quantifies their composition and growth characteristics.

Strengths

Capable of analyzing a variety of sample consistencies. Quantifiable results. Early as 24-hour turn-around. Doesn't require living/active samples. Additional Live/Dead differentiation test. Spore detection. More accurate and less conservative readings than MPN tests. Tests against the 10 most influential prokaryotes.

Weaknesses

Required minimum size sample from pipe of interest. Opportunity to increase the number of interrogated prokaryotes.

Manufacturers

GTI

Utilities Using Technology

Washington Gas, SoCal Gas, Aera Energy, National Oil-Well, Saudi Aramco

References

Application of Real-Time Quantitative PCR (qPCR) in MIC Monitoring in Oil and Gas Industries

Section 2.8: Tools, Non-Destructive Examination and Testing

Electro Magnetic Acoustic Transducer (EMAT)

Method

Metal Loss Detection

Description

EMAT technology can provide accurate wall thickness measurements, using no couplant, by inducing a variety of guided waves into the nearby steel. The technology is very effective at detecting areas with wall loss, defects, gouges, and especially areas with stress corrosion cracking; areas that exhibit the highest risk for future corrosion or failure.

Strengths

EMAT scans do not require couplant to take wall thickness measurements and make wall loss calculations. Works well on corroded surfaces and can indicate severity of corrosion through the steel. The external sensor is capable of scanning large diameter pipes.

Weaknesses

Manufacturers

Sonic Sensors, Sonatest, Structural Integrity Associates, Inc.

Utilities Using Technology

Multiple

References

http://www.sonicsensors.com/

EMAT technology is a spot-check transducer requiring that an area of pipe be scanned repeatedly until enough information has been captured to profile the entire cross-section of pipe.

Guided Wave

Method

Electro-Magnetic Waves (EMW)

Description

The Magnetostrictive Sensor Guided-Wave MsSR3030 instrument pulses a 32kHz signal into the pipe via a wire-ribbon ring attached circumferentially around an exposed segment of the pipeline. The echoed waveforms are analyzed and identified as pipeline features such as welds, pipe supports, bends or tees, and flanges. The system will also respond to pipe flaws and corrosion pits, making this a suitable method for pipeline inspection.

Strengths

The ribbon-cable sensor rings are wrapped around the pipe of interest, capable of coupling securely to any diameter pipe. The system includes a PC and accompanying analysis software to record the feedback signals. The inexpensive sensor rings induce transverse guided wave is much less expensive than other technologies (e.g. piezo-induced guided-wave), while still providing detailed information about the pipeline. This feature allows for the installation of a permanent sensor ring, providing year-round monitoring of pipeline assets.

Weaknesses

Although highly sensitive to anomalies in the pipe wall, the MsSR3030 cannot distinguish coating flaws from wall defects. A good coating is assumed where there is no metal loss. Additionally, asset information of the pipeline system may be helpful to distinguish standard pipeline components from sections of wall loss and corrosion. The unit does not have communication capabilities; data must be transferred manually for back office reporting.

Manufacturers

Southwest Research Institute

Utilities Using Technology

Not widely adopted

References

http://www.swri.org/4org/d18/nde/mss.htm

Liquid Penetrant Testing (LPT)

Method
External Crack Detection

Description
LPT, also called Penetrant Testing (PT) and Dye Penetrant Inspection (DPI), is a low-cost inspection method used to locate surface-breaking defects in all non-porous materials (metals and plastics, or ceramics). It is used to detect surface defects such as hairline cracks, surface porosity, leaks in new products, and fatigue cracks on in-service components.

Strengths
Simple, low-cost, can be done in the field.

Weaknesses
Surface detection only. The pipe needs to be exposed in order to conduct the test.

Manufacturers
Trytech, Multiple others

Utilities Using Technology
Multiple

References
ASTM E 1417, Standard Practice for Liquid Penetrant Testing

Magnetic Particle Testing (MT)

Method
External Crack Detection

Description
MT is a process for detecting surface and subsurface discontinuities in iron and steel pipes. The process puts a magnetic field into the pipe. The presence of a crack or surface discontinuity allows the particles to build up at the discontinuity and form an indication.

Strengths
Simple, low-cost, can be done in the field.

Weaknesses
Surface detection only. The pipe needs to be exposed in order to conduct the test.

Manufacturers
Multiple

Utilities Using Technology
Multiple

References
ASTM E 709 Guide for Magnetic Particle Testing Examination

Radiography/X-ray Analysis

Method

Radiography/X-ray

Description

Inspection of welds is required by the Code of Federal Regulations part 192. X-ray inspection provides a tried and true means for examination of welds for integrity analysis. It is capable of detecting internal and external defects with high resolution field or laboratory scans.

Strengths

The device is portable and it can create 3D images. Standard inspection method. Very good tool for inspection of welds.

Weaknesses

Radiation concerns. Need access to the pipe to do the inspection. More difficult to do inspection when the pipe is in service, ie need to use pig/crawler to inspect pipeline. Only provides a snapshot in time of the integrity of the pipe.

Manufacturers

GE, Multiple

Utilities Using Technology

Multiple

References

http://www.ge-mcs.com/download/it-common/GEIT-10012EN_ndt-brochure.pdf

Ultrasonic Testing (UT)

Method

Metal Loss Detection

Description

Pulse-waves with frequencies ranging from 0.1-15 MHz and occasionally up to 50 MHz (B-scan) are launched into materials to detect internal flaws or to characterize materials. The technique is also commonly used to determine the thickness of the test object (for example, to monitor pipework corrosion).

Strengths

This method can be applied to both the internal and external sides of the pipe. A successful reading will produce a wall thickness readout and metal loss indicator. A-Scan transducers will get spot-check thickness readings. B-Scan transducers will get a 2 dimensional scan equivalent to 240 A-Scans, significantly decreasing the time need to profile a pipe section.

Weaknesses

UT testing provides a single spot check only meaning that more than one measurement is required when profiling a pipe for consistent wall thickness. Additionally a couplant is required to accurately measure thickness of steel.

Manufacturers

Multiple, Panametrics-NDT

Utilities Using Technology

Multiple

References

ISO/DIS 17640, Non-destructive testing of welds - Ultrasonic testing of welded joints. Structural Integrity

External Guided Wave

Method

Metal Loss Detection

Description

GUL Wavemaker 4 /Teletest Focus+ use piezoelectric transducers to transmit Ultrasonic guided waves transversely, along the pipe, to locate corrosion spots, defects, and wall loss. This method must be used as a sorting or screening tool, not a measurement tool. While most commercially available versions are temporary inspection tools and moved down a pipe during a survey, GUL makes a Permanently Installed Monitoring System (PIMS) compatible with Wavemaker.

Strengths

The guided wave device completes a 100% volumetric scan of the pipe and propagates in either direction. From one location, the device scans up to a 400m length of pipe with a modest sensitivity of 5% wall loss detection. Under ideal conditions, the sensitivity reaches 1%. Pipe OD of up to 36" can be scanned. A major benefit of GUL inspection is that the line remains in service during inspection.

Weaknesses

The transducer array harness is designed for specific pipe OD. This device is not designed to be keyhole accessible, and needs exposed pipe with enough clearance for the transducer belt. Quality of the return signal depends heavily on pipe insulation and coatings. The optimal scenario requires the pipe to be bare or its coating be well bonded, to have a gaseous product, to be above grade, and to have straight lengths of pipe with no tees. Highly trained workers are required to interpret the output signals and filter through erroneous data. The device has a "dead zone" located a few inches on either side of the transducer. Longitudinal cracks are not detectable, unless the wall loss is greater than 3% and the torsional wave is used. Lastly, relative wall thickness changes are measured, as opposed to absolute wall thickness measurements.

Manufacturers

Team, Inc. (Alvin, TX)
Guided Ultrasonics LTD. (GUL)
Teletest

Utilities Using Technology

None

References

BG Group - Pipeline Coating ILI Techniques_KK Input.docx
http://www.teletestfocus.com/teletest-focus-plus/teletest-focus-plus.jsp

AGA 12 Encryption

Method

SCADA and RTU

Description

GTI-developed standard for encrypting messages relayed by RTU's and SCADA equipment to prevent cyber-hacking of critical pipeline control systems. This is a standardized method of hacking prevention, available as an option on top of standard protocols to enhance security. This was industry introduced in 2006.

Strengths

Robust, effective method to inhibit hackers from decrypting highly sensitive SCADA information. .

Weaknesses

Old technology, designed for modem speeds and serial connections. Not widely adopted although recommended by AGA.

Manufacturers

N/A

Utilities Using Technology

N/A

References

http://igs.nigc.ir/igs/OTHER/AGA-12-SCADA.PDF

www.symantec.com/

Remote Terminal Units (RTU)

Method

SCADA and RTU

Description

A low-power remote unit that provides system critical information to the SCADA system. The SCADA system then sends commands to the RTU's based on the interpretation of this data. Various options exist. Bristol's ControlWave, Allen Bradley's DataSite, Fisher's ROC-800

Strengths

Robust, rugged, expandable, scalable, standardized communication protocol, Ethernet-based security and speed. Compatible with HART and MODBUS communications systems.

Weaknesses

Compatibility or lack of integration into existing utility's GIS.

Manufacturers

Emerson, Rockwell Automation

Utilities Using Technology

Multiple

References

http://www2.emersonprocess.com/en-US/brands/remote/rtus/Pages/RTUs.aspx

MODBUS. HART. FIELDBUS.

Method

Communication Protocols

Description

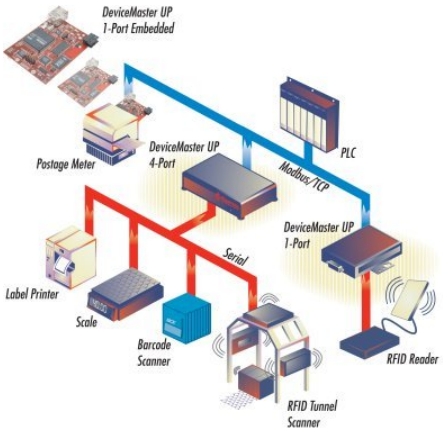
Standardized communication protocol that offers expandability and security. Mesh network and IP/TCP addressable. Used by the RTU to communicate with the controllable peripherals (valves, pressure sensors, etc.) Digital signal that is superimposed on the analog sensor reading.

Strengths

HART is the community leader in sensor and SCADA array communications protocols. Both are widely adopted and standardized.

Weaknesses

Many other protocol options are available thus finding interchangeable parts can be a limiting factor.



Manufacturers

Multiple

Utilities Using Technology

Multiple

References

http://comtrol.congruentdev.com/pub/en/Modbus-TCP-Gateway-to-Serial-Device-Communication

http://www.modbus.org/

Valve

Method

Remotely Controlled Block Valve

Description

A valve that is remotely controlled to stop the flow of gas. The Emerson FieldQ device provides intelligent control of a pipeline by integrating a pneumatic actuator, switchbox and solenoid to open and close the connected rotary valve. The device will provide enough mechanical force, safety features, and pressure isolation to reliably open and close the valve.

Strengths

The device can be controlled by a SCADA system or a user's direct input. A large position indicator is visible by the user.

Weaknesses

More expensive than a manually operated valve. Requires communication lines wired up to the control box for integration into the desired control system.

Manufacturers

Multiple (Emerson , Fisher, FieldQ)

Utilities Using Technology

Multiple

References

Emerson Process Management

Check Valve

Method

Valve

Description

A valve that automatically blocks gas to prevent backflow in the system. Frequently installed at compressor stations. Requires a minimum static pressure to allow flow through.

Strengths

A check valve prevents gas from flowing in the undesired direction. This is performed mechanically and does not rely on electricity for operation nor does it not require user interaction or SCADA control The failsafe will close the valve.

Weaknesses

This valve has not adjustable components, limiting the minimum "on" pressure to be defined by the manufacturer. It lacks an intelligent state controller that could relay information into a SCADA system to remotely monitor the valve's condition.

Manufacturers

Keckley

Utilities Using Technology

Multiple

References

http://www.keckley.com/retainerless-wafer-body-check-valves.html.htm

System Modeling

Method

Stoner Pipeline Simulator (SPS) Model

Description

The Stoner model incorporates a comprehensive list of attributes including product specifications, pipe types and components, fittings, surrounding terrain and protection systems into a transient fluid flow simulation that is used throughout the industry to assist in the design of pipeline systems.

Strengths

Capable of modeling heat transfer, pipe flow, gas composition, corrosion, leaks, compressor start-up and shut-down sequences, regulator setpoint changes and upset conditions, regulators, valves, headers and heat exchangers, and control systems. Combining all these components and assets is one way in improving a utility's IMP and preparing for maintenance.

Weaknesses

A possible gap is the integration in to a live GIS system so that the developed models can be directly tied to and compared to the real working system. Even so, the Stoner model does not incorporate neighboring utilities or CP interference sources

Manufacturers

GL Noble Denton

Utilities Using Technology

Multiple

References

http://www.gl-nobledenton.com/en/software/product_suites/sps.php

Isograph's Reliability Workbench

Method

Fault Tree Analysis (FTA)

Description

Hierarchies of cause-and-effect clauses that represent all possible scenarios for a given system are integrated to better prepare for and predict inspection, repair, maintenance schedules, and infrastructure lifecycles.

Strengths

Comprehensive results that help identify new scenarios and conditions that may never have been realized in the field. Using the FTA to design a cause and effect relationship between seemingly unrelated components can potentially help improve utility IMPs and more accurately plan pipeline maintenance and prioritize spending.

Weaknesses

Although the rewards can be great, the technology is expensive to develop requiring databases of information to extrapolate and then populate the tree with. Once established, a high degree of training is necessary to flatten the learning curve.

Manufacturers

Isograph

Utilities Using Technology

Multiple

References

http://www.isograph-software.com/

Cellular

Method
Use of cellular data as a means of communication.

Description
Utilizing the growing wireless infrastructure of 3G cellular communication to monitor critical system data. Communication via cellular data is used for several monitoring systems and can be integrated with many devices. Some manufacturers create dedicated systems that integrate with sensors on the pipeline.

Strengths
Readily available in many areas, large coverage areas. Expanding reliability.

Weaknesses
Inconsistent connection, coverage limitations.

Manufacturers
Multiple

Utilities Using Technology
Multiple

OnRamp Wireless

Method
Wireless Communication Infrastructure

Description
OnRamp Wireless has created a specially designed wireless infrastructure targeted for the low bandwidth, high node-count DAQ systems, typically required of utility SCADA networks. A 2.4 GHz radio tower can communicate with up to 64,000 sensors nodes within a 40-mile, open-air radius. Each capable of capturing critical pipeline data using its on-board sensor inputs.

Strengths
Highly advanced communication network that finds a niche in the low bandwidth, high capacity data transmission market. The 2.4 GHz frequency band is unlicensed and enables low power devices to work efficiently. Direct Sequence Spread Spectrum data modulation provides a means for high noise immunity and a high number of sensor nodes.

Manufacturers
OnRamp Wireless

Utilities Using Technology
Multiple, in multiple industries

References
http://onrampwireless.com/products/access-point/

Weaknesses

Needs to be integrated with sensors that have communication capabilities. The system requires a power source that must be maintained regularly. The documentation provides no indication of protection circuits or redundancies to isolate real-world electrical environments from this advanced communication radio. Also, this system has the potential to knockout lower-power Wifi and Bluetooth networks in the transmitter's radius.

Phone Line

Method

Wired SCADA Data Control

Description

Dedicated phone line provides consistent and reliable communication for monitoring critical system data. Many SCADA systems are wired with phone lines used to communicate with the servers. It is a secure means of communication.

Strengths

Reliable, direct connections to SCADA systems. Secure.

Weaknesses

Expensive to install over long distances.

Manufacturers

Multiple

Utilities Using Technology

Multiple

Fiber Optic

Method

Wired SCADA Data Control

Description

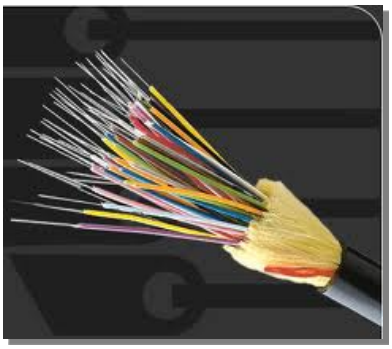
Fiber optic cable installed along pipe capable of transferring high fidelity information over long distances. This method of communication is highly reliable. Fiber optic can be used to not only communicate with control systems, but also monitor disturbances in the soil providing an indication for potential damage to the pipeline system.

Strengths

High bandwidth. Infrequent base stations. Fast and reliable means of communication or monitoring.

Weaknesses

Very expensive to install, usually with new installations. It is



Manufacturers

Multiple

Utilities Using Technology

Multiple

difficult to “retrofit” or install new fiber optic along existing pipelines.

References

http://www.aip.org/tip/INPHFA/vol-8/iss-1/p18.pdf

Human Machine Interface (HMI)

Method

Wired SCADA Data Control

Description

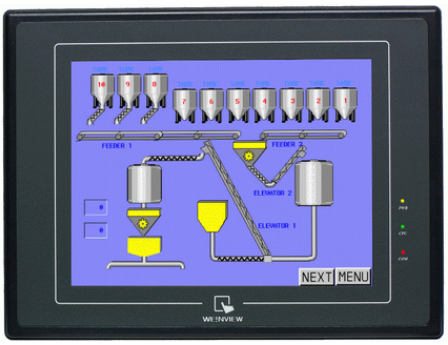
Human Machine Interface, in association with hardware communication protocols such as MODBUS or HART, make up a networked system of devices to allow human control of industrial machinery to maintain a widely compatible interface.

Strengths

The HMI network establishes a link between a variety of sensors and automation mechanisms and a control box for easy system interpretation and management. The interface is customizable in accordance with the application. High frequency of industrial use, with a large group of manufacturers and suppliers. Wireless functionality and touch screen interfaces can condense a complicated control room into a much more manageable system.

Weaknesses

Highly specific designs mean that each HMI must be preconfigured for each application; there is no key-hole solution for HMI control systems.



Manufacturers

Red Lion Controls, Parker, Siemens, Advantech, others

Utilities Using Technology

Multiple

References

Picture source
http://www.advantech.com/products/Human-Machine-Interfaces/sub_1-2MLK4R.aspx

Geographical Information System

Method

GIS Data Collection

Description

Use of a mapping system to keep records and maintain an accurate visual depiction of all pipelines in system. May follow certain models of data storage such as APDM and ICAM. Personnel, assets, components, installations and maintenance records are some of the data sets commonly stored in GIS systems.

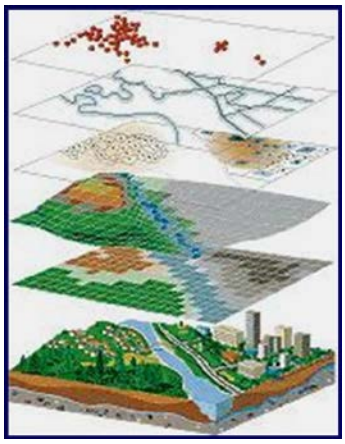
Strengths

A GIS is a database system that extracts pieces of information and organizes and presents them visually such that the user can

interpret all the critical information regarding a job site, employee, item supply chain, item location or entire pipeline readily. This promotes better maintenance scheduling as well as more certain location information of assets.

Weaknesses

Data entry into a system like a GIS requires back office labor and translation of handheld GPS loggers, utility's proprietary job records, automatic welding machine data, and other various industry tools into a format that the GIS can use. This can be onerous as standardization of data sets among the GIS community is not realized.



Manufacturers

Smallworld, esri'sArcGIS, Integraph

Utilities Using Technology

Multiple

References

GTI SME

http://rmbl.info/gis/gisbackground.html

Microwave Communication

Method

Wireless SCADA Data Control

Description

Microwave communication relies on a line-of-sight link between a minimum of two base stations, capable of spanning great distances and providing reliable, high bandwidth data communication. Although typically applied to Cell networks or broadband internet service, microwave technology can be applied to a private and secure SCADA system to relay sensitive information over great distances and at high data throughput.

Strengths

A microwave radio system can be deployed quickly as it does not require buried cables or complex routing stations. Obstacles that may have caused issues for fiber or cable networks are avoided. Typical range is 30% farther than optical horizon. Point-to-multi-point supported.

Weaknesses

Requires physical line-of-sight linkage between transceivers and

Manufacturers

Trango, Freewave

Utilities Using Technology

Colorado-based EnCana

References

http://en.wikipedia.org/wiki/Microwave

usually mounted on towers to extend the range of communication. Infrastructure cost is can outweigh the benefits as some SCADA systems do not require or will ineffectively use the high bandwidth capabilities.

Work Management System

Method

Asset Management Software

Description

A work management system is a software program that manages the various stages of a project lifecycle. It provides a maintenance work management solution for activities including long- and short-term planning, maintenance scheduling, schedule management, and resource optimization. It is capable of consolidating large amounts of project information in one accessible location and can serve as means to distribute tasks and function as a record keeping device.

Strengths

Provides organization and location for all project-related information. Can be used to create project records as well as assign tasks, and track costs.

Weaknesses

Can be expensive to install company-wide. Can be time-consuming to use and difficult to implement.

Manufacturers

Maximo, WMS, Storms, Multiple others

Utilities Using Technology

Multiple

References

http://www-01.ibm.com/software/tivoli/products/maximo-asset-mgmt/

APPENDIX D:
Emerging Technology Development Roadmap

Figure 7: Emerging Technology Development Roadmap

Emerging Pipeline Integrity Assessment and Monitoring Technology

Projects*

Strategic Element	Program Area	2013 Q1	2013 Q2	2013 Q3	2013 Q4	2014 Q1	2014 Q2	2014 Q3	2014 Q4	2015 Q1	2015 Q2	2015 Q3	2015 Q4	2016 Q1	2016 Q2	2016 Q3	2016 Q4	2017 Q1	2017 Q2	2017 Q3	2017 Q4
What's Where	Data Standards and Guidelines					National Utility As-Built Standard/New/CEC															
			ASTM F2897-11/New/CEC																		
			Asset Tracking Guidelines/Ongoing/OTD																		
	Tracking and Traceability					Lifecycle Tracking of Specs & Procedures/Ongoing/OTD															
		Long Term Traceability/Available/Not is Regular Use																			
	Records Management	Geographic Information system (GIS)/Available/Requires Upgrading																			
	Database Integration	GIS Barcode Decoding Tool/Ongoing/OTD																			
	Field Data Capture	Hand-Held Data collection Device/Ongoing/OTD																			
								Mobile Device Area Network/New/CEC													
		High Accuracy GPS/Ongoing/OTD																			
		Bar Coding for Asset Tracking/Ongoing/OTD																			
			RFID Tags for Asset Tracking/New/TBD																		
			Pipe Rover Platform for Above-Ground Surveys/Proposed/SMP																		
System Communications and Control	Interoperability	Interoperability Standards/Ongoing/OTD																			
	Control - AMI	AMI Capability Verification/New/CEC																			
	Control - System	Transmission EZ Valve/Proposed/SMP																			
System Monitoring and Assessment	MEMS - UC Berkeley	MEMS Sensor Development/Ongoing/UC Berkeley																			
	Monitoring Devices for ROW Encroachment and Excavation Damage Prevention		GPS Based EEN for ROW Monitoring/New/GTI																		
		ROW Damage Detection and Operational Improvement/New/UC Berkeley																			
		Learning Algorithms for PIGPEN Warning System/Ongoing/PHMSA																			
	Monitoring Devices for Leak Detection	Mobile Leak Detection - Picarro/Ongoing/PG&E and Others																			
		Smart Pipeline Network - Pipe & Repair Sensor System/Ongoing/PHMSA																			
		Acoustic Leak Detection for High Pressure Pipeline/Proposed/OTD																			
	ILI for Unpiggable Pipelines	Explorer Series of Robotic Inspection Platforms/Ongoing/NYSEARCH																			
		Pipecrawlers/Ongoing/Pipecrawlers																			
		EMAT for Unpiggable Pipe/Proposed/OTD and PRCI																			
		Dry Hydro – Phase 2/Proposed/SMP																			
	In-Line Inspection (ILI)	Internal Inspection Optimization (IIO)/New/OTD, PRCI, INGAA Foundation																			
		Laser Ultrasonic Testing (LUT)/Ongoing/UC Berkeley																			
		Real-Time Pipe Movement Detection/Proposed/SMP																			
		UT Tool and Sensor Improvements/Ongoing/PRCI																			
		EMAT/Ongoing/OTD and PRCI																			
	Above Ground Inspection	Coating Disbondment Detector/Ongoing/SMP																			
	Direct Assessment	Validation of 3D Scanners for Anomaly Assessment/Proposed/OTD																			
	Methods for Stress Assessment	Quan. Non-destructive Residual Stress Asessment Tool/Ongoing/PHMSA																			
	Mechanical Damage	Programs focused on Impacts of Mechanical Damage to Pipelines/Ongoing/PRCI																			
	Corrosion	Program focused on Internal, SCC, and External Corrosion/Ongoing/PRCI																			
	Methods for Risk Assessment	Interactive Threats in Kiefner/NYGAS & other Models/Ongoing/NYSEARCH																			
Overarching Issues	Program Coordination	Focus on Safety/Ongoing/CEC																			
		Lessons Learned and Technology Demonstration Workshop/New/CEC																			
	Education	Larger Resource Pool/New/CEC																			
		Improvements in Situational Awareness/New/CEC																			
		Primer on Integrity Management/New/CEC																			
		Situational Information/New/CEC																			
				Real Time Knowledge to Situation – Video Link to Advisor/New/CEC																	
	Advocacy	Innovative Rate Recovery for New Tech Development/New/CEC with CPUC																			
		Regulatory Acceptance of New Technologies/New/CEC with CPUC																			

*Projects are shown by Title/Status (New, Proposed or Ongoing)/Lead Organization or CEC if To Be Determined and Color Shows Timeline and Priority of Involvement by CEC (High = Red, Medium = Green, Low = Blue)

APPENDIX E:
Technical Tasks from Statement of Work – Energy Commission 500-10-050

Task 2 Baseline Technology Assessment for Pipeline Integrity and Monitoring Technology in the State of California

The goal of this task is to perform a comprehensive review of the current state of technology being used in California to manage pipeline integrity and safety.

The Contractor shall:
Assess the state of technology (hardware, software, and processes) being used in California to assess and monitor the condition and health of the natural gas pipeline network.

Specific topics of this task will include (but are not limited to):
1. Internal and external assessment and inspection methods,
2. Long-term condition monitoring techniques,
3. Risk-modeling and incident prediction tools,
4. ROW encroachment and excavation damage prevention,
5. Detection of pipeline leaks and ruptures,
6. Remote stress/strain analysis of pipelines,
7. Tools, techniques, and data analysis methods utilized in integrity management programs,
8. Nondestructive examination and analysis methods,
9. Automated, semi-automated, and manual methods for system shutdown,
10. System modeling of incident responses and shutdown, and
11. Data collection and communication technologies.

Deliverables:
- Task Report

Task 3 Assessment of Currently Available Pipeline Integrity Assessment and Monitoring Technology

The goal of this task is to assess all the available technology that could be used in California, but is not currently being used because it is either: (a) ready for use but not widely used on a commercial basis, (b) unknown, or (c) unproven.

The Contractor shall:
- Identify immediate opportunities to improve the assessment, monitoring, and integrity management program of the California pipeline network.
- Rank these opportunities based on impact, value, timeline, and feasibility.
- Catalogue all currently available pipeline integrity related technologies.
- Clearly define which pipeline assessment and monitoring needs could be immediately filled with commercially available technologies.

- Develop a gap analysis between the currently practiced or available pipeline integrity technologies and what is recommended to further enhance pipeline safety

Deliverables:
- Catalogue of Available Technologies
- Gap Analysis

Task 4 Evaluate Emerging Pipeline Integrity Assessment and Monitoring Technology

The goal of this task is to identify emerging technologies to enhance pipeline integrity that could be developed and implemented within two to four years based on technical merit, applicability, reliability, cost effectiveness, and degree of enhanced safety.

The Contractor shall:
- Recommend specific hardware, software, and practices that could be considered. A broad array of technologies will be considered, including (but not limited to):

1. Hardware, sensors, software, and/or process solutions,
2. Land, air, and space (satellite) based platforms,
3. Robotics and internal inspection technologies,
4. Communication pathways through the smart energy grid such as wireless and SCADA networks, and
5. System automation, response, and simulation modeling techniques.

- Provide a report that prioritizes (by impact, feasibility, and timeliness) emerging technologies that could be developed to enhance pipeline safety, assessment, monitoring, and overall system integrity that could be implemented within four years.
- Place special emphasis on the development of a strategy to integrate the use of the AMI communications backbone, currently being installed or enhanced in California. This will optimize the value of the AMI system and the performance of the pipeline monitoring and safety technologies identified or developed for implementation.

Deliverables:
- Task Report

Task 5 Implementation Plan to Introduce New Pipeline Integrity Assessment and Monitoring Technologies to the California Pipeline Network

The goal of this task is to recommend specific technologies and the actions necessary to implement them in a timely and cost effective manner. This could include laboratory and field testing of new technologies as well as further development of emerging technologies.

The Contractor shall:
- Provide a testing, deployment, and implementation plan for currently available technologies.
- Provide recommendations for the development of select emerging technologies.

- Provide recommendation for the development of new technologies to meet outstanding gaps.

Deliverables:

- Implementation Plan

APPENDIX E:
Interview Guide

Figure 8: Interview Guide

INTERVIEW GUIDE

CALIFORNIA NATURAL GAS PIPELINE ASSESSMENT

CEC Project 500-10-050

The basis for the project and this interview comes from three of the tasks included in the objectives these tasks are to:

- Perform a comprehensive review of the current state of technology being used in California to manage pipeline integrity and safety.
- Assess all the available technology that could be used in California, but is not currently being used because it is either: (a) ready for use but not widely used on a commercial basis, (b) unknown, or (c) unproven.
- Identify emerging technologies to enhance pipeline integrity that could be developed and implemented within two to four years based on technical merit, applicability, reliability, cost effectiveness, and degree of enhanced safety.

This interview and the collection of the resulting information will focus on the specific task of documenting the pipeline integrity and monitoring technologies currently in use in California. With that introduction, the following are the interview questions that we will be discussing:

1) This project is focused on pipeline integrity and monitoring technologies for transmission mains. The first step is to establish a clear understanding of what your company considers to be in the category of transmission. Please provide your company's definition of a natural gas transmission pipeline?
   a) Examples:
      i) Greater than 20% SMYS (Specific Minimum Yield Strength)
      ii) Operating pressure greater than 124 psi

2) There are a variety of tools and monitoring systems used for pipeline integrity. Some are actual hardware, a "pig" used in an In-Line Inspection, others are software used to receive and interpret data for purposes of alarming or for trend analysis and predictive maintenance. The next set of questions are to identify the technology (hardware, software, and processes) being used in California to assess and monitor the condition and health of the natural gas pipeline network. Please indicate which tool(s) or monitoring system(s) you use in each category.

CATEGORY	USED Y/N	SPECIFIC TECHNOLOGY(IES)
Internal and external assessment and inspection methods		
Long-term condition monitoring		

techniques		
Risk-modeling and incident prediction tools		
ROW encroachment and excavation damage prevention		
Detection of pipeline leaks and ruptures		
Remote stress/strain analysis of pipelines		
Tools, techniques, and data analysis methods utilized in integrity management programs		
Nondestructive examination and analysis methods		
Automated, semi-automated, and manual methods for system shutdown		
System modeling of incident responses and shutdown		
Data collection and communication technologies		

3) Are there any tools or monitoring systems you have used in the past that you no longer use. If so which ones were used in the past and why are they no longer used? For example, is the tool or monitoring system:
   a) No longer available?
   b) Determined to be ineffective?
   c) Was there a gap in the capabilities? If so, what was that gap?
   d) Difficult or dangerous to use?

e) Replaced by a method that became the industry standard?
f) No longer allowed by regulation?

4) Is your company evaluating the use of an alternate commercially available tool or monitoring system?

   a) If so, what are you considering and what is the basis for your decision to consider making a change?

5) Is your company involved in the development of a new or replacement tool or monitoring system that would be used on your system?
   a) If so, which one(s) and what were your company's reasons for participating in the development?

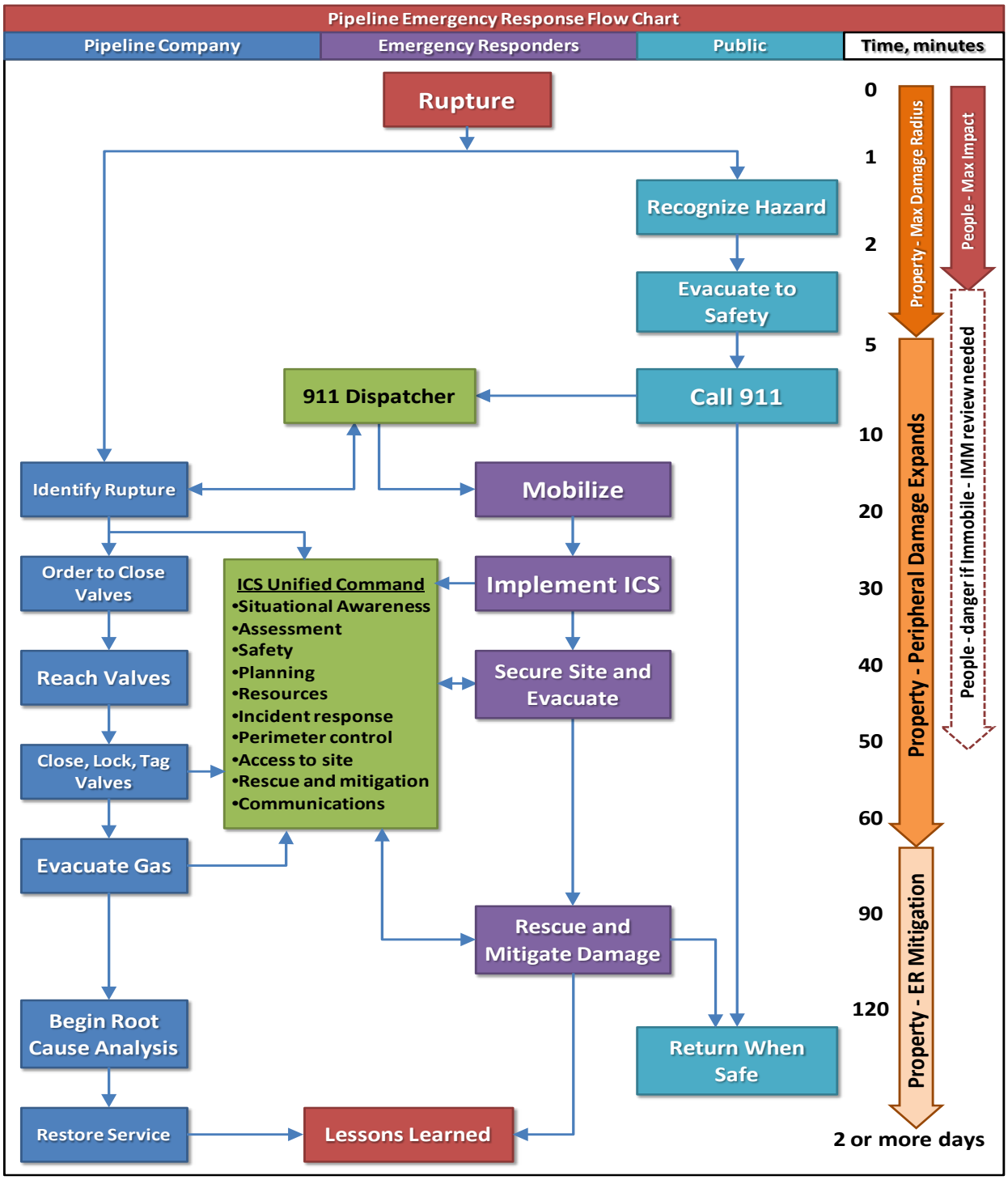
   b) What improvements are anticipated?

6) Are there any items related to pipeline integrity and monitoring we missed that should be included?

APPENDIX G:

Natural Gas Pipeline – Guidance on Emergency Response Time Reduction. INGAA, April 27, 2012

Figure 9: Pipeline Emergency Response Flow Chart and Tables



Pipeline Company		
Improvement Area	**Activities During Event**	**Improvement Considerations**
Pre-Incident	N/A	• Where using ASV's/RCV's, operate with crossovers closed where possible • Companies take FEMA 100, 200 and 300 courses in Incident Command System

Identify Rupture	Company and public are trying to determine whether the event is associated with pipeline company assets and to determine the location of the rupture.	• Develop situational awareness within pipeline companies that drives toward a decision to close valves based on limited information
		• Establish company specific rupture determination and decision making guidelines by controller coverage zones (develop decision tree[s])
		• Add SCADA points/alarms to better focus controllers attention on safety
		• If preliminary information appears to identify a potential rupture
		  o Call local emergency dispatch
		  ▪ 1) inform actively seeking to confirm
		  ▪ 2) Request information on citizen reports
		  ▪ 3) Call back to emergency dispatch to confirm
		• Examine crossover settings (closed or automated)

Pipeline Company		
Improvement Area	**Activities During Event**	**Improvement Considerations**

Order to Close Valves	Make the decision and give the order to close valves to isolate the rupture.	• Enable empowerment through training on situational awareness around the decision to close valves based on limited information.
		• Re-educate customers on culture change
		• If personnel response time to mainline valves on either side of a high consequence area exceeds one hour (under normal driving conditions and speed limits) from the time the event is identified in the control room, provide remote valve control through a supervisory control and data acquisition (SCADA) system, other leak detection system, or an alternative method of control.
		  • Beginning from the time the event is identified (for example when Gas Control is convinced of the rupture).
		  o Ending when personnel arrive at the valve (and begin to close the valve)

Reach Valves	Dispatch personnel to reach manually operated valves.	• Install ASV/RCV in HCA's where reaching valve is greater than 1 hour (consider pipeline flow conditions when deciding which technology to use) • Consider dispatch of multiple employees to valves (rupture site, upstream and downstream valve, backup sites) • Improve on-call availability • Enlist local emergency dispatch for assistance getting to the site, as necessary (addresses traffic and weather) • GIS on company vehicles for knowing who is most favorably located to respond • Pre-establish process for critical staff to enter site (e.g. natural disaster or tight security event)

Pipeline Company		
Improvement Area	**Activities During Event**	**Improvement Considerations**
Close, Lock and Tag Valves	Closing, locking and tagging manually operated valves or the time that it takes for ASV/RCV valves to actuate and reach closure.	• Valves with OD ≥ 20" equipped with an assisted operator to speed valve closure (e.g. push button operation, commercially available turn reduction technology, portable operators) • Ensuring devices for assisting in valve operation are properly supplied for use (e.g. portable operators, reservoir tanks for pneumatic operators, etc.) • Mobilize to lock out and tag out. • Provide guidance on staying away from site until lock out and tag out is complete.

Evacuate Gas	Once valves are closed there is a time lag that is necessary for the natural gas product, which is lighter than air, to blow down to atmospheric pressure. As the pressure drops in the isolated segment, the flame impact radius will be reduced to a point where emergency crews may begin to encroach the vicinity of the rupture by communicating with the pipeline company.	• Operator should provide information regarding timing of valve closure and cessation of gas flow
		• Open blow offs (where safe) to assist with evacuation of gas
		• Run downstream compressor or meter stations to assist with evacuation of gas
		• Use threaded versus flanged blow off caps
		• For replaced pipe, establish valve spacing following guidance in ASME B31.8-2010, paragraph 854.4(b) which references the following:
		  o Where a short section of line is replaced additional valves would normally not be required.
		  o Where the replacement section involves a contiguous mile or more of transmission line, additional valve installation shall be considered to conform to the spacing requirements for new pipeline construction in 192.179.

Begin Accident Root Cause Analysis	Evaluate the cause of the accident sufficiently to determine if it is safe to restore service.	• Make an initial review of the cause of the accident. • Interview eye witnesses. • Collect damaged sections of pipe for later analysis. • Determine if it is safe to restore service

Pipeline Company		
Improvement Area	**Activities During Event**	**Improvement Considerations**
Restore Service	Restore service to a pressure based on safety, regulator input and other factors.	• Agree on a plan to safely restore service involving regulators and the customers. • Execute the plan.
Lessons Learned	Meet with emergency responders and local officials to determine lessons learned.	• Meet as soon as practical following the incident to determine what went well and what can improve.

Emergency Responders		
Improvement Area	**Activities During Event**	**Improvement Considerations**
Pre-Incident	N/A	• Train 911 dispatchers in pipeline emergency response (include in API 1162 Public Awareness programs) • Make street level maps available to county local emergency planning center (MAOP's, diameter, valve location, centerline) – shape files and pdf • Include in street level maps Potential Impact Radius (PIR) calculation, estimate for timing of valve closure, dissipation time following valve closure, and heat factor of gas (e.g. varies depending on type of gas) • Promote National Pipeline Mapping System (NPMS); better distribution of NPMS; more information on NPMS • Include in street level maps Potential Impact Radius (PIR) calculation, estimate for timing of valve closure, dissipation time following valve closure, and heat factor of gas (e.g. varies depending on type of gas) • Develop industry standard incident response checklist (pamphlet) for frontline emergency responders. [emphasize safety of people] • Develop mobile apps with detailed information for emergency responders • Develop clear list of contacts for local emergency responders • Develop site specific emergency response plans (for company, facility and emergency responders) for locations with confined personnel (e.g. detention center, nursing home, etc.)

Emergency Responders		
Improvement Area	**Activities During Event**	**Improvement Considerations**

Call to 911	Calls made to the 911 dispatch center and there is some confusion as to whether this is a pipeline rupture or something else. The location of the incident is being determined.	• Pipeline company call 911 to tell that there "may" be an event
		  o Pipeline company request 911 to identify whether received calls about an incident in area
		  o Pipeline company establish point of contact for 911 dispatcher
		  o Pipeline company work with 911 dispatcher as initial point of contact to initiate situational awareness. Pipeline representative to review with 911 dispatcher PIR, timing of valve closure, dissipation time and heat factor.

Mobilize	Emergency Response forces are mobilized to the rupture site. Initially, there is not full knowledge of what type of emergency this is. Initially setting up the Incident Command.	• Company representatives join unified incident command at the incident site within 30 minutes to an hour • Pipeline company work with emergency responders to assist getting to the site • Reference industry standard checklist for actions to take in responding to incident (to be developed). • Refer to mobile app with detailed information for emergency responders (to be developed)

Implement Incident Command	Implement the Incident Command System.	• Establish Unified Command with pipeline operators and utilities
		  o Pipeline company immediately connect with responder's incident command
		  o Pipeline company to establish method with responders for sustaining situational awareness
		• Reference list of company contacts provided to county emergency personnel.

Emergency Responders		
Improvement Area	**Activities During Event**	**Improvement Considerations**
Secure site and Evacuate	Emergency Responders set up a secure perimeter around the rupture site to keep the public safe and begin the process of evacuating people from the rupture site.	• If ignited, reverse 911 to initiate evacuation to an established list • If not ignited, escape without creating ignition sources • Establish a perimeter to keep people out based on PIR, valve closure timing, gas dissipation rate, heat factor, and local variables such as climate, topography, population density, demographics, and suppression methods available • Review risks with emergency responders through direct and effective communications • Establish process for critical company staff to enter site • Reminder on training of local officials and responders on our operations (facilities, expectations)
Rescue and mitigate damage	Begin the process of rescuing personnel first and beginning the process of mitigating damage second.	• Refer to site specific emergency response plans (for company, facility and emergency responders) for locations with confined personnel (e.g. detention center, nursing home, etc.) • Improve awareness and pipeline emergency response plans for detention centers, etc. • Enter area to rescue and mitigate damage once valves are closed, locked and tagged and gas has been evacuated.

Emergency Responders		
Improvement Area	**Activities During Event**	**Improvement Considerations**
Lessons Learned	Both emergency responders and pipeline company personnel develop lessons learned from an incident. Pipeline company communicates to its employees lessons learned and conveys those pertinent lessons learned to the emergency response community. In addition, the emergency response community communicates lessons learned within the emergency response community and shares those with pipeline companies.	• Following any incident develop lessons learned • Develop learning site or leverage a site like Lessons learn.gov • Incorporate emergency response to pipeline incidents into Emergency Responders' toolkit in Ready.gov • Improve use of mock drills and include emergency responders • Incorporate HSEEP (Homeland Security Exercise Evaluation Program) methods and evaluation into mocks • Support PIPA (Pipeline Informed Planning Alliance) • Training to emergency responders by industry (traffic control, fire, evacuation, etc.) • Continually evaluate emergency response and public awareness effectiveness • Initiate decision-support from senior leadership to gas operations when decisions were made to shut-in service to protect public safety

APPENDIX H:
NTSB Pipeline Accident Reports from 1969 through 2012

Figure 10: NTSB Pipeline Accident Reports from 1969 through 2012

	Date, Report No.	Accident type & Location	Pipeline & material transported	Owner	Cause of Accident
114	July, 2010 PAR-12-01	Hazardous Liquid Pipeline Rupture and Release, Marshall, MI	30-inch grade X52 steel pipe wrapped in single layer of polyethylene tape, carrying crude oil operating at 486 psig	Enbridge Inc.	Corrosion fatigue cracks that grew and coalesced from crack and corrosion defects under disbonded polyethylene tape coating. Deficient integrity management procedures allowed the well-documented cracks to propagate until failure.
113	September, 2010 PAR-11-01	Natural Gas Transmission Pipeline Rupture and Failure, San Bruno, CA	30-inch natural gas steel transmission main operating at 375 psig	Pacific Gas and Electric	Inadequate quality assurance and quality control in 1956 lead to ductile crack growth and fatigue crack growth of longitudinal seam weld. An inadequate pipeline integrity management program, which failed to detect and repair or remove the defective pipe section.
112	December, 2008 PAB-10-01	Explosion, Release, and Ignition of Natural Gas, Rancho Cordova, CA	2-inch Aldyl A main at 55 psig, natural gas distribution	Pacific Gas and Electric	A section of unmarked and out-of-specification polyethylene pipe was installed that had inadequate wall thickness that allowed gas to leak from the mechanical coupling
111	November, 2007 PAR-09-01	Pipeline Rupture of with release and ignition of Propane, Carmichael, MS	12-inch steel grade X-52 installed in 1961, coal tar enamel coated and felt wrap, 1405 psi carrying liquid propane	Dixie Pipeline Company	Failure of longitudinal seam weld in an electric resistance welded (ERW) pipe
110	March, 2008 PAR-08-01	Leak explosion and fire Plum Borough, PA	2-inch 5L Grade B steel pipe, coal tar enamel coating & CP. Installed 1961, at 10 psig. Natural gas distribution	Dominion Peoples Natural Gas	An excavator struck the pipeline with the backhoe 5 years before the accident, stripping the pipeline of its protective coating and making the pipeline susceptible to corrosion and failure.
109	October, 2004 PAR-07-02	Pipeline rupture and leak with vapor cloud, Kingman, Kansas	8.625-inch carbon steel pipe, 5LX, grade X46, with an ERW welded seam, and CP, at 981 psig Hazardous liquid, Anhydrous ammonia	Magellan Midstream Partners, L.P.	Pipe gouge created by heavy equipment damage to the pipeline during construction in 1973 or subsequent excavation activity at an unknown time that initiated metal fatigue cracking and led to the eventual rupture of the pipeline

108	December, 2005 PAR-07-01	Pipeline break, explosion, and fire Bergenfield, New Jersey	1-1/4 inch steel natural gas distribution service line, 30-36 inches deep, operating at 11.5 psi.	Public Service Electric and Gas Company	The service line was subjected to shifting soil during excavation, which resulted in damage to the service line and the release and migration of natural gas into the apartment building.
107	August, 2004 PAR-06-01	Leak, explosion, and fire DuBois, Pennsylvania	500-foot length of 2-inch Aldyl coiled pipe, butt fused to a previously installed 2-inch coiled pipe. Natural gas at 50 psig	National Fuel Gas Distribution Corporation	Fracture of a defective butt-fusion joint and the failure to have an adequate program to inspect butt-fusion joints and replace those joints.
106	April, 2003 PAR-04-02	Storage Tank Explosion & Fire, Glenpool, OK	80,000-barrel storage tank, Diesel fuel.	Conoco-Phillips Company	Ignition of a flammable fuel-air mixture within the tank by a static electricity discharge
105	July, 2002 PAR-04-01	Rupture and Release of Crude oil Cohasset, Minnesota	34-inch, 5L, grade X52, with a double Submerged arc weld (DSAW) longitudinal seam weld, coated with a spiral wrap tape. Constructed in 1967.	Enbridge Pipelines, LLC	Inadequate loading of the pipe for transportation that allowed a fatigue crack to initiate along the seam of the Longitudinal weld during transit.
104	July , 2003 PAR-04-01	Rupture, explosion, and fire Wilmington, Delaware	1-1/4 inch steel service line, 6-8 in water column, Natural gas	Delmarva Power and Light Company	Failure of the excavator to verify that all underground facilities were marked within the proposed dig site before beginning excavation
103	August , 2000 PAR-03-01	Natural Gas Pipeline Rupture and Fire Carlsbad, New Mexico	30-inch, grade X52 Natural gas at 675 psi	El Paso Natural Gas Company	Significant reduction in pipe wall thickness due to severe internal corrosion.
102	June, 1999 PAR-02-02	Pipeline Rupture and Fire, Bellingham, Washington	16-inch steel pipeline grade X52 at 1,370 psi. Refined petroleum products	Olympic Pipe Line Company	Damage during 1994 construction of water treatment plant project, inaccurate evaluation of ILI results, which led to not excavate and examine the damaged section of pipe.
101	April , 2000 PAR-02-01	Rupture of Oil Pipeline and Release of Fuel Oil Chalk Point, Maryland	12-in, 5L grade X42 ERW weld steel pipe, 1-inch polyurethane thermal insulation and a PE jacket exterior coating	Potomac Electric Power Company	A wrinkle in a section of pipe that had been field-bent during initial construction of the pipeline in 1971 and 1972. A fracture in the buckle was undiscovered because ILI inspection data were interpreted inaccurately as representing a T-piece.

100	March, 2000 PAR-01-03	Pipe failure and leak Greenville, Texas	28-inch, API 5LX, Grade X-52, DSAW (double seam submerged-arc welded) steel pipe at 705 psig, Gasoline	Explorer Pipeline Company	Corrosion-fatigue cracking that initiated at the edge of the longitudinal seam weld at a likely pre-existing weld defect.
99	January, 2000 PAR-01-02	Hazardous liquid pipe failure and leak Winchester, Kentucky	24-inch, API 5L, X-52, steel pipe Crude oil	Marathon Ashland Pipeline, LLC	Fatigue cracking due to a dent in the pipe, in combination with fluctuating pressures within the pipe, produced high local stresses in the pipe wall
98	February, 1999 PAR-01-01	Liquid petroleum pipeline rupture Knoxville, Tennessee	10-inch Grade 5L X-42, ERW weld, steel pipe at 91 psig Diesel fuel	Colonial Pipeline Company	pipe rupture initiated by environment-induced cracking in an area of pipe coating failure
97	January, 1999 PAR-00-01	Rupture, explosion, and fire Bridgeport, Alabama	¾-inch steel natural gas service line at 35 psig	Utilities Board of the City of Bridgeport	Third party construction activities, resulting in damage to natural gas service line
96	December, 1998 PAR-00-01	Natural gas pipeline rupture, St Cloud, MN	1-inch high pressure plastic pipe		Construction of utility pole anchor struck and ruptured the underground gas service line
95	July, 1998 PAR-01-01	Natural Gas Explosion and Fire, South Riding, Virginia	3/4-inch-diameter polyethylene gas service line	Northern Virginia Electric Cooperative & Washington Gas Light Company	Corrosion and subsequent overheating and arcing at a splice in one of the conductors of the triplex electrical service line and inadequate separation between the electrical conductors and the gas service line.
94	March, 1998 PAR-99-01	Pipe failure and leak Morgan Falls Landfill, Sandy Springs, Georgia	40-inch-diameter welded steel pipe at pressure 384 psig, Gasoline	Colonial Pipeline Company	settlement of soil and compacted trash underneath the pipeline,
93	July, 1997 PAR-99-02	Pipeline Rupture and fire Indianapolis, Indiana	20-inch steel Natural gas transmission pipeline at 310 psig	Citizens Gas & Coke Utility	Directional drilling operations carried out in the proximity of existing underground facility.

92	November, 1996 PAR-99-03	Hazardous liquid overpressure rupture Murfreesboro, TN	8-inch Grade X-42, Electric Resistance Weld (ERW) steel pipe at 1,820 psig. Diesel fuel	Colonial Pipeline Company	Failure of the pipeline operator to follow company procedures for operating the pipeline causing overpressure.
91	August, 1996 PAR-98-02	Pipeline Rupture, Liquid Butane Release, and Fire Lively, Texas	8-inch-diameter steel LPG (liquefied petroleum gas) pipeline transporting liquid butane	Koch Pipeline Company, LP	The rupture occurred under a roadway in a subdivision due to corrosion in desponded tape coating.
90	June, 1996 PAR-98-01	Pipeline rupture and release of oil Fork shoals, South Carolina	36-inch-diameter Fuel Oil	Colonial Pipeline Company	River crossing - No adequate management controls in place to protect the corroded pipeline at the Reedy River crossing
89	October, 1996 PAR-98-01	Natural Gas pipeline rupture & Fire, Tiger Pass, LA	a 12-inch-diameter submerged steel pipeline at 930 psig	Tennessee Gas Pipeline	River Crossing - Unallocated pipeline across Tiger Pass before that location was dredged.
88	May, 1996 PAB-98-01	Release of Gasoline Gramercy, Louisiana	1,094 psig 20-inch steel pipe	Marathon Pipe Line Company	excavations of a nearby pipeline
87	October , 1994 PAB-98-02	Natural Gas Explosion and Fire Waterloo, Iowa	1/2-inch plastic pipe at steel tapping tee to steel main at 25 psig	Midwest Gas Co.	stress intensification, primarily generated by soil settlement at a connection to a steel main, on a 1/2-inch mechanical compression connection to polyethylene pipe that had poor resistance to brittle-like cracking
86	November, 1996 PAR-97-01	Propane gas explosion San Juan, Puerto Rico	Propane gas	San Juan gas Co. , Inc.	an excavation-caused gas leak
85	June, 1994 PAR-96-01	Natural Gas Distribution Explosion Allentown, Pennsylvania	2-inch-diameter steel gas service line 55 psig	UGI Utilities, Inc.,	Excavation caused gas line separated at a compression coupling.

84	March, 1994 PAR—95-01	Natural gas pipeline explosion and fire Edison, NJ	36-inch at 790 psig	Texas Easter Transmission Corp	Mechanical damage induced gouge to the wall that reduced thickness
83	April 1992, PAR-93-02	Highly volatile liquid, Brenham, Texas	Salt dome storage cavern	MAPCO Natural Gas Liquids, Inc.	Inadequate overfilling of the underground storage system
82	January, 1992 PAR-93-01	Overpressure in gas distribution system, Chicago, IL	Overpressure in regulator system to 10 psig in a distribution line	People Gas Light	Failure to control pressure causing overpressure in a low distribution line
81	December, 1990 PAR-92-01	Natural gas explosion and fire Fort Benjamin Harrison, Indiana	Gas system valve	DOD/Army	Inadvertent opening of a valve to a discontinued steel gas main.
80	March 1990, PAR-91-01	Liquid Propane pipeline North Blenheim, NY	8-inch liquid propane In52 ft casing 12.75 in outside diam. and 0.25 in wall thickness under 8 ft of soil	Texas Eastern Products Pipeline	Ruptured within a casing beneath County Road 43 due to repair work (spacers) to clear an electrical short on the 8-inch steel pipe in casing. The improperly supported pipe has high bending stress in location of small stress-corrosion cracks
79	October, 1989 PAR-90-02	Natural gas Gulf of Mexico, Sabine Pass, TX	Offshore 16-inch transmission line		Submerged pipeline The skeg at the bottom of the vessel struck the pipeline.
78	May 1989 PAR-90-02	San Bernardino, CA	Petroleum pipeline	Calney Pipeline	Derailment of freight train causing rupture in pipeline
77	September 1988- March 1989 PAR-90-01 PAR-90-03	Natural gas 5 incidents in Kansas and Missouri	- corrosion damage in 3 service lines and 2 cast-iron mains	Kansas Power and Light company	Corrosion damage, corrosion and pullout, third party and graphitization,
76	August, 1988 PAR-89-01	Natural Gas Green Oaks, Illinois	4-inch plastic main at 35 psig	North Shore Gas Company	Backhoe struck line during repair operation by gas company due to failure to locate lines

75	January, 1988 PAR-88-01	Natural gas explosion & Fire Winston-Salem , NC	2-inch service line	Piedmont natural Gas	Corrosion failure of gas service line
74	July, 1986 PAR-87-02	Liquid pipeline rupture Mounds View, MN	8-inch gasoline pipeline	Williams Pipeline Co.	Weld seam corrosion in low frequency electric resistance weld and inadequate CP
73	March, 1986 PAR-87-01	Natural gas explosion Chicago Heights, IL	¾-inch wrapped steel line at 28 psig	Northern Illinois Gas Co.	Backhoe pulled the service line from compression coupling
72	March, 1986 PAR-87-03	Gas explosion & fire Fort Worth, TX	2-1/2 inch Service line at 22 psig	Lone Star Gas Co.	Rupture of service line by a backhoe
71	February, 1986 PAR-87-01*	Natural gas rupture & fire Lancaster, Kentucky	30-inch natural gas at 986 psig	Texas Eastern Gas Pipeline Co.	Low CP due to shield by a rock formation below the pipeline
70	April, 1985 PAR-87-01*	Natural gas rupture & fire Beaumont, Kentucky	30-inch natural gas at 990 psig under State Highway 90	Texas Eastern Gas Pipeline Co.	Undetected atmospheric and electrolytic corrosion reduced wall thickness within the casing
69	December, 1985 PAR-86-02	Natural gas explosion & fire Derby, Connecticut	3-inch cast iron gas main at 1 psig	Northern Utilities Service Co.	Construction activities resulted in undetected fracture of the cast iron pipe
68	August, 1985 PAR-86-01*	Pinson ,Alabama	Natural liquefaction plant	Alabama Gas Corp.	Failure of a weld in aluminum tank and release of methane
67	July, 1985 PAR-86-01*	Pipeline rupture and Fire Kaycee, Wyoming	8-inch diameter , petroleum refined products at 430 psig	Continental Pipeline Co.	Girth weld cracked during recoating

66	February, 1985 PAR-85-02	Natural gas explosion & fire Sharpsville, PA	6-inch Aldyl A gas main in coupling at 50 psig at railroad crossing	Natural Fuel Gas Co.	Pullout of a pipe from compression coupling due to thermal contraction of PE pipe inside the casing
65	November, 1984 PAR-86-01	Jackson, LA	30-inch transmission at 1,000 psig	Texas Eastern Gas Pipeline Co.	Poor compaction of soil backfill beneath pipe caused stresses when heavy equipment operated above the pipe
64	September, 1984 PAR-85-01	Nature gas explosion & fire Phoenix, AZ	1-1/4 inch ABS plastic gas main at 30 psig	Arizona Public Service Co.	Weakening from internal environmental stress cracking
63	October, 1983 PAR-84-04	Explosion & fire South Charleston , WV		Columbia Gas of West Virginia, Inc.	
62	October, 1983 PAR-84-03	Natural gas explosion & fire Fairfax, VA	Gate station	Washington Gas Light Co.	
61	September, 1983 Par-84-05	Natural gas overpressure explosion & fire Boston, MA	High pressure in a low pressure gas system	Boston Gas Company	Failure of oversized weights to monitor gas regulator
60	July, 1983 PAR-84-02	Natural gas explosion & fire Clear Lake, Iowa		Interstate Power Co.	
59	March, 1983 PAR-84-01	Liquefied petroleum gas West Odessa, Texas	8-inch LPG qt 1,075 psig	Mid America Pipeline System	Pipeline gouging when struck by a powered auger
58	May, 1983 PAR-83-04	Natural gas explosion & fire Bloomfield, New Mexico	Compressor station, failed gasket at 815 psig	El Paso Natural Gas Co.	Improper tightening of compressor head bolts
57	October, 1982 Par-83-03	Natural gas flash fire, Pine Bluff, Arkansas	¼- thick steel plate welded to cap a 22-inch transmission line blew off at pressure 260 psi	Mississippi River Transmission Corps.	Leaking of gate valve caused pressure to blew the isolated cap

56	November, 1982 PAR-83-02	Natural gas explosion & fire Hudson, Iowa	20-inch transmission line at 820 psig	Northern Natural l Gas Co.	Puncture of the line by a contractor tile plow
55	June, 1982 PAR-83-01	Natural gas explosion & fire Portales, New Mexico	¾-inch steel service line connected with a compression coupling to 1-¼ inch line	The Gas Co. of New Mexico	Damaged service line pulled out by a contractor backhoe at a compression coupling
54	January, 1982 PAR-82-03	Natural gas Centralia, Missouri	¾-inch pressure regulator at 0.4 psig. Rupture caused 47 psig pressure main to enter the system	Missouri Power & Light Co.	Rupture of pressure regulator by a backhoe
53	September, 1981 PAR-82-02	Explosion & fire Ackerly, Texas	Refined petroleum products, 12-inch steel pipe at 1,100 psig	The Chaparral Pipeline	Pipe rupture when struck by rathole drill
52	August, 1982 PAR-82-01	Gas pipeline puncture San Francisco, CA	16-inch main at pressure 32 psi	Pacific Gas & Electrical Co.	Puncture by a drill used by a contractor to set tiebacks for excavation shoring
51	December , 1980 PAR-81-04	Pipeline rupture & fire Long Beach , CA	10-inch steel pipe carrying naphtha	Four Corners Pipeline Co.	Overpressure of the pipeline and rupture at location thinned by internal corrosion
50	October, 1980 PAR-81-1	Independence, Kentucky	2-inch compression coupling upstream a gas meter, connected to 4-in main at 165 psig	Union Light, Heat & Power Co.	Overpressure and separation of compression coupling.
49	April, 1980 PAR-81-03	Gasoline explosion & fire Roseville, MN	Cast iron section in station at 72 psig	Williams Pipeline Co.	Fracture of base of cast iron pump
48	March, 1980 PAR-81-2	Refined petroleum products pipe failure Manassas & Locust Grove, VA	32-inch at 702 psig	Colonial Pipeline Co.	Pressure surge initiated by automatic shutdown of a pump station and caused failure in 2 pre-existing defects in a crier pipe thinned by corrosion

47	February, 1980 PAR-80-08	Natural gas explosion Cordele, GA	1-inch service line at 22 psig	Gas Department of Cordele	Snagging of line by a backhoe and pulled out from compression coupling.
46	January, 1980 PAR-80-06	Petroleum products rupture Bayamon, Puerto Rico	8-inch API, 5L X-42, ERW, gasoline	The Pipelines or Puerto Rico, Inc.	Rupture by a bulldozer.
45	October, 1979 PAR-80-04	Natural gas explosion Washington, DC	1-inch plastic service line inside a1.25 in casing and coupled to 6 in steel main	Washington Gas Light Co.	Separation of service line from its compression coupling due to construction work
44	October, 1979 PAR-80-03	Natural gas rupture Stanardsville, Virginia	3-inch steel gas main at 15 psig	Columbia Gas of Virginia, Inc.	Excavation equipment pulled a 1.25 inch service line
43	October, 1979 PAR-80-02	Cove Point, Maryland	LNG pump seal	Columbia Liquefied Natural Gas Corp.	Inadequately tightened seal
42	July, 1979 PAR-80-01	Natural gas rupture New Orleans, LA	14-inch transmission line on the bottom of 300 ft of water	Southern Natural gas Co.	Offshore pipeline damaged by a grappling hook from boat
41	May, 1979 PAR-79-03	Natural gas rupture Philadelphia, PA	8-inch cast iron gas main at 0.25 psig	Philadelphia Gas Works	Sagging & breaking of pipe due to soil erosion
40	January, 1979 PAR-79-02	Natural gas explosion & fire London, Kentucky	7-inch steel main at 17 psig, uncoated, no CP, at 0.25 psig	The Gas Service Co.	Corrosion hole
39	August, 1978 PAR-79-01	Liquefied Petroleum pipeline rupture & fire Donnellson, Iowa	8-inch LPG pipe, X52, ERW weld.	Mid America Pipeline System	Failure of pipeline due to combined stresses when lowered, and dent and gouge
38	June, 1978 PAR-78-5	Natural gas rupture & fire Kansas City, Missouri	10-inch steel pipe at 110 psig	The Gas Service Co.	Rupture of pipeline by heave excavating equipment

37	December, 1977 PAR-78-4	Pipeline explosion & fire Lawrence, Kansas	2-inch plastic gas main inserted in a 394 ft casing joined to steel main	Kansas Public Service Co.	PE pipe contracted 3.5 inch from compression coupling and pulled out.
36	December, 1977 PAR-78-03	Pipeline rupture Atlanta, GA	12-inch cast iron main at 10 psig	Atlanta Gas Light Co.	Pipe rupture by 8-inch steel I-Beam driven pipe
35	July, 1977 PAR-78-2	Crude oil Explosion & fire Fairbanks, Alaska	Pump station	Alyeska Pipeline Service CO.	Poorly coordinated procedures
34	July, 1977 PAR-78-01	Pipeline rupture & fire Ruff Creek, PA	12-inch propane pipeline at 450 psig	Consolidated Gas Supply Corp.	Stress corrosion cracking when subjected to earth subsidence
33	January, 1977 PAR-77-4	Natural gas explosion & fire Williamsport, PA	4-inch bare steel main at 10 psig	Pennsylvania Gas & Water Co.	Thermal contraction of weld in pipe
32	December, 1976 PAR-77-03	Natural gas explosion & fire Robstown, Texas	Compressor at 1,000 psig	Exxon Gas Systems, Inc.	Failure of studs securing vale cover due to stress fatigue and tension
31	August, 1976 PAR-77-02	Natural gas explosion & fire Allentown, PA	4-inch cast iron main wit bell & spigot joints in 12 ft, at 1 psig	UGI Corp.	Cast iron was weakened structurally by localized graphitization and undermined by a sinkhole
30	August, 1976 NTSB-PAR-77-1	Pipeline rupture & fire Cartwright, LA	20-inch API 5L X-46 ERW natural gas pipe at 770 psig	United Gas Pipeline Co.	Rupture by a road grader equipment
29	June, 1976 NTSB-PAR-76-8	Pipeline rupture Los Angeles, CA	8-inch, API 5L X-46 pipe Carrying gasoline	Standard Oil CO. (SOCAL)	Rupture by excavation equipment
28	August, 1975 NTSB-PAR-76-7	Pipeline rupture & fire Romulus, Michigan	8-inch, API 5L steel pipe carrying propane	Sun Pipeline CO.	Propagation of surface cracks due to abnormally high pressure in dented & gouged section

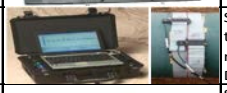
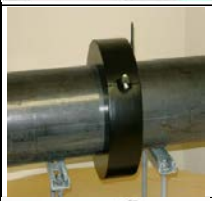
27	January, 1976 NTSB-PAR-76-6	Pathfinder Hotel Explosion & Fire Fremont, Nebraska	2-inch Aldyl-A plastic pipe inside 4-inch steel pipe. Natural gas.	Nebraska Natural Gas Co.	Contraction of PE pipe caused pipe to pull off from compression coupling
26	May, 1975 NTSB-PAR-76-5	Explosion & Fire Devers, Texas	8-inch pipe API 5LX-60 (ERW weld). Natural Gas Liquids (NGL) at 1,425 psig	Dow Chemical	Pipe gouged by a backhoe
25	January 1975 NTSB-PAR-76-3	Terminal Fire Lima, Ohio	Flange rupture in terminal Crude Oil	Mid-Valley Pipeline Company	Motor-operated valve closing against oil stream causing pressure to build.
24	December, 1974 NTSB-PAR-76-4	Abilene, Texas	26-inch API 5LX-52 crude oil at 750 psig	West Texas Gulf Pipeline Co.	Pipe settlement caused a leak in a cracked fillet weld on a full-wrap repair sleeve
23	June, 1974 NTSB-PAR-75-2	Transmission Pipeline Bealeton, VA	30-inch Natural Gas at 700 psig	Transcontinental Gas Pipeline Corp.	Hydrogen stress crack propagation
22	May, 1974 NTSB-PAR-76-1	Pipeline failure Meridian, Mississippi	6-inch API 5LX-42 (ERW weld) Natural gas	Texas Oil and Gas Corp.	Internal corrosion and hydrogen embrittlement
21	April, 1974 NTSB-PAR-76-2	Explosion at 305 East 45th Street, NY	hydro-pneumatic pressure tank next to gas line	Consolidated Edison Co.	Rupture of overpressure hydro-pneumatic tank tearing service gas line
20	March, 1974 NTSB-PAR-75-3	Transmission Pipeline Farmington, NM	12-inch Natural Gas 500 psig	Southern Union Gas Co.	Brittle fracture of longitudinal flash weld due to localized crevice corrosion
19	March, 1974 NTSB-PAR-75-1	Transmission Pipeline Monroe, LA	30-inch Natural Gas transmission pipeline constructed in 1956	Michigan-Wisconsin Pipeline Co.	Girth weld failure inside casing under a highway due to repeated soil stresses. Contributing to the stresses was the position of the pipe inside casing and heavy clay soil surrounding the pipe at each end of casing.

18	December, 1973 NTSB-PAR-74-6	Conway, Kansas	Pipeline rupture Anhydrous Ammonia	Mid America Pipeline System	Above-normal pressure on a pipe section weakened by previous damage by outside force
17	December, 1973 NTSB-PAR-74-4	Charleston, WV	2-inch gas main at 39 psig	Columbia Gas of West Virginia, Inc.	2 corrosion holes in gas main
16	June, 1973 NTSB-PAR-74-5	Gas explosion & Fire Bowie, Maryland	½ inch PE pipe	Washington Gas Light Co.	Stress crack due to occluded particle causing a stress point
15	December, 1972 NTSB-PAR-74-3	Explosion & Fire Clinton, Missouri	4-inch Cast-iron main at 17 psig	Missouri Public Service Co.	Crack of cast-iron main due to soil stresses & railroad vibration
14	April, 1973 NTSB-PAR-74-2	Natural gas explosion El Paso, TX	6-inch cast iron main reduced to 2-inch welded steel line at 20 psig	Southern Union Gas Company	A broken cast iron reducer and two corrosion leaks in the main
13	February, 1973 NTSB-PAR-74-1	Explosion & fire Coopersburg, PA	8-inch bare steel gas main at 50 psig	UGI Corporation	Acetylene weld crack due to detonation of heavy dynamite charges
12	February, 1973 NTSB-PAR-73-4	Natural gas liquid fire Austin, TX	NGL in 10-inch line at pump station , 525 psig	Philips Pipeline Co.	Stress concentration due to improper welding repair
11	February, 1973 NTSB-PAR-73-3	Natural gas explosion Atlanta, GA	6-inch cast-iron main at 10 psig	Atlanta Gas Light Co.	Cast-iron main cracked due to uneven settlement
10	May, 1973 NTSB-PAR-73-2	Crude Oil Explosion Hearne, TX	8-inch bare steel ruptured at 530 psig	Exxon Pipeline Co.	Excessive internal pressure due to shut down and thin-wall condition caused by corrosion in unprotected steel wall
9	October, 1972 NTSB-PAR-73-1	Lake City, Minnesota	¾-inch steel service line	Northern States Power Co.	Service line struck by bulldozer and was pulled out from compression coupling at the main.
8	March , 1972 NTSB-PAR-72-4	Natural gas explosion Annandale, VA	2-inch wrapped-steel gas main at 22 psig	Washington Gas Light Co.	Backhoe snagged gas main
7	October, 1971 NTSB-PAR-72-3	North Richland Hills, TX	6-inch welded steel gas main at 25 psig, connected to 1 ¼ inch galvanized steel service line	Lone Star gas Co.	Broken service line connection with a 6-inch gas main, and gas migrated under the slab

6	November, 1971 NTSB-PAR-72-2	Natural gas distribution Pittsburgh, PA	Regulator station in underground vault	Equitable Gas Co.	Changing the valve in the vault without stopping gas flow
5	December, 1970 NTSB-PAR-72-1	Propane gas explosion Franklin County, Missouri	8-inch steel line ERW weld	Philips Pipeline Co.	Rupture of insufficiently bonded longitudinal weld & internal corrosion
4	September, 1970 NTSB-PAR-71-2	Petroleum products pipeline Jacksonville, Maryland	30-inch diameter coated steel pipe	Colonial Pipeline Co.	Flaw of undetermined origin in pipe wall
3	September, 1969 NTSB-PAR-71-1	Natural Gas line Houston, TX			
2	November, 1969 NTSB-PAR-70-1	Natural gas distribution Burlington, Iowa	Regulator pressure from 55 psig to low pressure	Iowa Southern Utilities Co.	Overpressure in the low pressure line due to bulldozer damaging the regulator
1	June, 1969 NTSB-PAR-69	Natural gas distribution Gary, Indiana	Shut off valve at regulator station	Northern Indiana Public Service Co.	Opening of a separation valve allowing gas at 20 psig to flow into the ¼ psig system

APPENDIX I:
Summary of Technologies

Figure 11: Internal and External Assessment and Inspection Methods – Commercial

EXAMPLES OF INTERNAL AND EXTERNAL INSPECTION TECHNOLOGIES				
Technology	**Description**	**Pictures**	**Strengths**	**Weaknesses, Limits or Gaps**
Close Interval Survey (CIS)	A method of measuring pipe to soil voltage potential along the pipeline that provides an indication of the level of cathodic protection provided.		Most utilized tool, provides pipe to soil potential for CP condition and shows coating damage	May not show disbonded coating, interference from other lines, requires holes in asphalt and concrete surfaces.
DCVG	Direct Current Voltage Gradient Survey (DCVG)		Accurate in coating damage, can indicate size of damage.	Not useful on bare pipes, interference from other lines, requires holes in asphalt and concrete surfaces.
ACVG	Alternating Current Voltage Gradient (ACVG) A-Frame		Connects to pipeline mappers (PCM) for pipe locating and depth, does not require drilling in asphalt, precise defect location	May not find disbonded areas
Magnetic Tomography	Transkor MTM. Detects flaws by finding stress points based on the disturbed magnetic domain structure that was defined at the pipe's creation.		capable of detecting impact flaws and corrosion.	Service surveys require an excavation after MTM scan and initial analysis. High pressure lines only. Requires slight (10 psi) alteration in pressure to stimulate sensors.
Guided wave	Magnetostrictive Sensor Guided-Wave (MsSR3030 instrument). (Low frequency or Acoustic)		Sensor Rings are created around the pipe, thus no diameter restrictions. PC based software. Detects pipe wall defects	Cannot distinguish coating flaws from wall defects.
Broadband Electromagnetic Technology	technology induces eddy currents to flow in close proximity to a transmitter/ receiver in a ferrous pipe. These currents migrate time, allowing a complete profile of the ferrous pipe to be obtained. The technique scans through the full wall of the pipe registering corrosion or flaws within the full wall thickness		Scanning is not limited by the diameter of the pipe. Equipment has the ability to survey through thick coatings (>2") of materials such as paint, tar, plastic, and concrete commonly found on many buried and exposed pipelines. The pipeline does not have to be taken off-line, as readings are taken from the outside of the pipe. Through-hole technology.	Unit might miss small detailed clusters of cracks. Rather it will indicate a wide/shallow depression of wall loss. Cannot differentiate from ID/OD ferrous loss. Reading based on % wall loss relative to "good" wall. Spot Check.
External Guided wave	GUL Wavemaker/Teletest Service. Transmits Ultrasonic guided waves transversely along the pipe to locate corrosion spots and defects.		100% volumetric scan. From one location, scan up to 400m length of pipe. Up to 36" diameter. Line remains in service.	early prototype. Transducer harness designed for specific diameters. Not keyhole accessible, needs exposed pipe.
Ultrasonic wall thickness - Eagle Array	Non-invasive wireless pipeline monitoring system that incorporates a set of ultrasonic sensors to monitor pipeline integrity and relays the data through a cloud-based reporting system.		Wireless connectivity. Rugged frame. Low power consumption. Attaches over assets' protective coating. Scheduled reporting. No interruption of service. No diameter limit. Measures: Temp., Humidity, Moisture, Vibration, Surface coating, Wall thickness, Corrosion rate. Works on FBE coated pipe.	Fitted for pipe diameter, Connectivity Issues, Antenna placement, IT involvement. Does not opperate on tar coated pipe.
Magnetic Flux Leakage (MFL)	PipeScan - adjustable (MFL) magnetic flux leakage pipe screening system		Proven/common technology. Locates internal metal loss. Surveys do not affect on-line product. Capable of scanning pipes up to 2.4m dai. 10 hour test time.	Requires exposed pipe. Max wall thickness 19mm. Hand push/pull, slow scan.
Borescope	XLG3 VideoProbe - 3D imaging probe capable of measuring distances and sizes of hard to reach defects in pipelines.		Directionally controllable tip. Remote viewer / controller. Internet connection. On the spot analysis. Variety of tip sizes	Large. Carrying around PC and power supply. Not for Hazardous environments.
Direct Assessment (in excavated pipe section)	Gouge & corrosion depth gauges. Visual inspection of exposed pipelines.		Relatively cheap. Just need to expose pipeline. Easy to visually diagnose problems	Can only detect problems on area of pipe that is exposed. Cannot determine potential problems to the internals of the pipeline.
Pipe Line Integrity Tester	Real time digital data acquisition for hydrostatic testing. Provides a means to automate the entire pressurization process and records critical parameters to verify pipeline integrity.		Plots data points vs time. Real time DAQ. Adheres to NIST standards. Roller case. Tolerance alert system	100lbs carrying bag. No connectivity/GIS integration

Source: GTI

EXAMPLES OF INTERNAL AND EXTERNAL INSPECTION TECHNOLOGIES - CONTINUED				
Technology	**Description**	**Pictures**	**Strengths**	**Weaknesses, Limits or Gaps**
ILI - MFL	Miniaturized MFL for distribution pipelines. Strong permanent magnets are used to induce a magnetic field axially allong the pipe. Node transducers will interpret loss of field strength, indicating a flaw.		Line remains in service and allows flow. 60 psi. Delivery rod system that tethers the unit for up to 1000 feet of pipeline in either direction. 4" pipe verified	Tethered only. Magnets can lock to internal pipe wall.
ILI-SMFL	Spiral MFL is an ILI tool that utilizes a spiral magnetization design that eliminates the need for two orthogonal magnetizers conventionally used with TFI tools. It creates an oblique field with no inspection gaps or hidden areas.		Effective at detecting anomalies associate with metal loss. Detects flux components in both the axial and transverse directions. Single magnetizer module. Improved classification of anomalies. Thetherless.	Must be used in conjunction with standard MFL and other measurement tools for practical anomaly distinction. Magnets can lock to pipe.
ILI -Locomotive RFEC	Explorer-II Remote Field Eddy Current (RFEC). Circumfrential wall thickness scans. The transducers are housed on an expanding ring located on one of the center modules. Other modules provide locomotion, visual sensors, power and computing operations.		up to 750 psi. Tetherless. Real time data stream and video feed. Fully encapsulated design. 2011 commercially available for 6-8 inch pipe as well as 10-14 inch pipe.	Large obstacles are inhibiting.
ILI - MFL and TFI	Strong permanent magnets are used to induce a magnetic field axially along the pipe. Node transducers will interpret loss of field strength, indicating a flaw. All products and services are commercially available. LIMITED INFO		Full packaged service. Proprietary analysis and visualization tools. It is a proven technology throughout the industry, and provides reliable wall-loss inspection	limited by pipe diameter. Primarily transmission line usage
ILI - EMAT	Inline inspection of pipeline wall thickness using EMAT technology, requiring no couplant. Very effective at detecting areas with wall loss or SCC.		no couplant needed. Wall thickness measurements, wall loss, SCC detection. Field test verified. NACE recognized as SCC detection method. Numerous circumferential EMAT's provide high resolution sensing	limited diameter pipelines

Source: GTI

Figure 12: Internal and external Assessment and Inspection Methods – Emerging

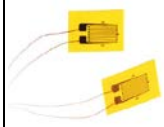
Emerging Inline Inspection Technologies				
Technology	**Description**	**Path to Market**	**Gap Fulfilled**	**Reference**
ILI - Guided wave	Tethered Guided-Wave Ultrasonic Inline-Inspection Heads. Low frequency guided wave design. Transducers propagate a signal transversely up to 15m and does not require couplant.	not fully developed, intense prepwork. 10" design only. Building prototype stage. Looking for testing areas.	Mapping capability, multiple and configurable ILI modules, non-flow restrictive tractoring drive, couplant sprayed to testing surface, expandable sensor heads. No couplant required. No pipe cleaning required.	Tethered Guided Wave
ILI	GE SmartScan - A set of cleaning and metal-loss detection pigs, specified with a facilitating hot-tap launching system .	While GE plays a large roll in pipeline inspection technologies, their most notable contribution has been the hot-tap launching system for their pigs. The sensors and tools mounted on the pigs are limited in their application and not suitable for unpiggable lines.	The Technology uses conventional Hall-effect sensors which is cost effective and convenient. The pigs and launcher are compatible with various multi-diameter pipe. Launching system can accommodate 1D bends and most notably, the device can withstand high speed travel in gas with pressures up to 1,450 psi., meaning no loss in service.	BG-Group Pipeline Damage Prevention/Mitigation Project Document http://site.ge-energy.com/prod_serv/serv/pipeline/en/insp_srvcs/metal_loss/smartscan/index.htm
ILI - Ultrasonic	IRISPig - Rotates ultrasonic transducers to measure wall thickness or metal loss during ILI. Pipe cleaning is required prior to deployment. Best suited on out-of-service lines only and must be water propelled using the water as a couplant for the sensors.	As of 2009, this technology is in its developmental stage and has been field-tested. IRISPig has reached a commercialization stage, however, further development may be	1.5 D bend capable. Diameters as low as 6" and 12" demonstrated, capable of greater than 20". Tethered or self-contained. No transducer to pipe wall contact.	BG GROUP
ILI - Locomotive MFL	TIGRE - a long-range, untethered inspection robot system, TIGRE, using a state-of- the-art Magnetic Flux Leakage (MFL) sensor, for the inspection of transmission and distribution pipelines under live conditions.	up to 750 psi. collapsible MFL design to navigate obstacles. Capable of inspecting "unpiggable" pipe. Mechanism to prevent unwarranted magnetic locking to steel.	limited to 10-26 inch pipe. Roll-out expected 2010. No further information	BG Group
EMAT	EMAT technology and tools require further assessment and application-based testing to highlight girth-weld inspection capabilities and accurate crack length measurements. This technology is commercially available and used, but improvements are still needed.	Although technology has reached a stage of maturity, improvements to the capabilites of EMAT in its ability to detect SCC, hydrogen induced cracks, fatigue cracks, hook cracks, and a variety of other irregularities and	EMAT technology offers couplant-less wall thickness measurements and anomaly detection of gaseous pipelines without purging or rigorous cleaning. This advancement may make EMAT ILI inspection one of the primary methods used to ensure a pipeline is Fit-For-Service.	
RFEC - Explorer-II	RFEC technology will be assessed and improvement modifications will be applied to allow an ILI technology to inspect areas with internal obstacles that may be impassable using conventional tools. This technology was integrated into the Explorer-II robotic platform upon its commercialization. It required a collapsible set of antennae to transverse tough obstacles.	Project was finished in 2009 with a successful prototype. Results show completion of assessment, antenna design and the adaptation to the unconventional robotic system. NOTE: the Explorer-II is commercially available.	Improved designed will allow for the inline inspections of small diameter pipelines, pipelines with casings, valves or other blockages.	http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=104
Laser Ultrasonic Testing (LUT)	Laser Ultrasonic Testing (LUT), is currently used in other industries for external inspections of a variety of materials that are strongly contoured such as railroad rails and aerial craft. Utilizing its abilities to penetrate metals without contact and derive accurate thickness measurements, toughness, ductility, and residual stress, this technology could prove useful and versatile from the perspective of an inline inspection PIG. The process does involve placing small stresses on the material to take measurements, which may be controversial.	This technology has been used in other industries but is awaiting adaptation and application to the natural gas industry.	The application of Laser Ultrasonic testing on natural gas pipelines for inspection purposes can bring more accurate and capable devices to the industry.	
InVista - Ultrasonic ILI Tools	This tool, developed by Quest Integrity Group, combines a circumferential high resolution ultrasonic sensor equipped pig with intelligent, back-office data analysis software that provides the utility with a detailed report indicating flawed areas and quantitative wall loss, as well as makes informed estimates of "Fitness-for-Service" metric. This advanced pipeline modeling software prioritizes degrees of wall loss and allows the utility to systematically schedule pipeline maintenance.	Invista has become a comprehensive solution for integrity management of pipelines. This technology and its accompanying software analysis algorithms put InVista in an up and coming tool that needs more widespread adoption by the industry.	It offers a complete pipeline integrity inspection suite with advanced high resolution ultrasonic wall thickness measurement hardware and the analytical and predictive management software to go with it. It operates on pipe diameters as low as 3" and up to 12". It's capable of making a 1D turn and transverses via a liquid line product (water or petroleum). Unlike other ILI tools, the Invista can detect both circumferential and longitudinal flaws in a single pass.	http://www.pipelineconference.com/sites/default/files/papers/McGee.pdf

Source: GTI

Emerging External Inspection Technologies				
Technology	**Description**	**Path to Market**	**Gap Fulfilled**	**Reference**
ART (Acoustic Resonance Technology)	This technology injects precise acoustic signals into pipe insulation or the pipe wall itself to detect the presence of moisture and/or derive an accurate wall thickness measurement. The acoustic waves act in such a way that they create a half-wave resonance within the pipe wall. The reflected signals are analyzed and are computed to derive critical pipeline attributes.	This technology is used in a commercialized tool from Gassco, a research company, however further extrapolation of the technology into other applications and tools is imminent. Adjustments made to the external inspection technology could find its way in other extreme climate	The technology can penetrate through the insulating material found on unburied pipe due to the low frequencies. With the resonance effect, water can be detected, indicating an area of possible corrosion and thus a definitive point to inspect. No couplant is need for this technology for both internal or external inspection methods.	http://www.gassco.no/wps/wcm/connect/Gassco-EN/gassco/home/presse/ons2008/innovation
Acoustic Signal Processing	In 2004, German company FINO AG developed a metal loss detector for use on buried pipelines. The technology required two points of contact with the pipe, and can scan up to 500m in one pass. It utilizes a low and high frequency harmonic signal to detect losses in pipe material as it passes through the outermost layers of steel.	This project was completed in 2005 showing successful field-tests after hardware and software improvements. Further development is needed for final product.	A utility company can perform non-destructive evaluation of pipelines and locate defects as an alternative to DA without unnecessary, costly excavation.	http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=122
Ultra-Low Frequency Imaging	An above ground utility locator for plastic and cast iron joints and pipes. This technology is better than GPR and utilizes fundamentally different techniques than GPR that theoretically will improve permeation through clay and difficult terrain. Also captures horizontal and vertical pipe location information.	Developmental work was completed by Nysearch in 2008, as this technology underwent its commercialization assessment, meaning that it's on its final stretch out into production.	Locating and identifying buried utilities with improved GPR performance and resolution.	http://primis.phmsa.dot.gov/rd/mtgs/020707/MarkAndraka.pdf
Meandering Winding Magnetometer	Meandering Winding Magnetometer (MWM)-Array technology can be adapted to externally inspect coated or insulated pipelines to detect corrosion, SCC and metal deformations. Operates without couplant and can permeate through coatings up to 2 inches, making it a very valuable piece of inspection technology.	SCC and deformation identifying testing proved successful during this developmental stage. Further work could include adaptation for internal use as an ILI tool and thus shrinking and ruggedizing the apparatus.	This technology offers a new approach to metal loss detection and defect identification that eliminates the need for couplant and the associated cleaning steps.	http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=235
Magnetostrictive Guided Wave	SwRI's Magnetostrictive Sensor guided-wave, long-range inspection tool is capable of capturing critical pieces of information regarding a pipeline's components. The hope here is to expand its capabilities to evaluate damage severity, capture ID/OD wall loss with improved accuracy , identify areas of circumferential cracks, and improve accuracy of locating artifacts.	This commercial technology needs to be made field-ready, assessed and validated for more widespread use.	Inspection of unpiggable pipelines and cased pipelines requires torsionsal guided wave technology, however further work is required to identify defects and distinguish pipeline characteristics	http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=197
Coating Disbondment Detector - Magnetic Field Propogation	The Coating Disbondment Detector consists of a device mounted on a wheel that is walked along the length of the pipe, picking up electromagnetic signals impressed onto the pipe from an access point. Electromagnetic interference captured by the device may indicate areas of coating disbondment or holiday.	Ongoing, the investigative efforts of this project are being provided by GTI for SMP. Preliminary results are promising, several improvements have been identified and more testing is required to validate the	Coatings of various types are applied to pipe to protect against corrosion. Coating disbondment provides an opportunity for corrosion to take place. To-date no technology exists that can detect coating disbondment without excavation.	GTI Research Programs
3D Structured-Light Scanners	This project is focused on the validation of one or more laser or structured light 3D scanning tool(s) that, if successful, would eliminate the manual data collection of in-the-ditch anomaly measurements, improve data quality and increase operational efficiency.	This is a new project initiated by OTD in the fall of 2012 with the projected completion by the end of the third quarter of 2013.	Operators are required to further assess anomalies found during direct assessment of ILI inspections to determine the need for repair. The accuracy, repeatability and reliability of pit gauge measurements are dependent on the skill and experience of the user and may be difficult to obtain if the anomaly is on the side or bottom of the pipe.	GTI Research Programs

Source: GTI

Figure 13: Remote Stress/Strain Analysis of Pipelines – Commercial

EXAMPLES OF REMOTE STRESS/STRAIN ANALYSIS TECHNOLOGIES				
Technology	**Description**	**Pictures**	**Strengths**	**Weaknesses, Limits or Gaps**
Ring Expansion Testing	Destructive testing where a "ring" sample of pipe is placed on a machine capable of mimicking high pressures inside the pipe. The picture shows a 76mm ring cut from the pipeline under going yield testing.		Verifies SMYS of a section of pipeline. Verifies wall thickness of section.	Does not test entire length of pipe (only small section).
Fiber optic	A fiber optic cable is taped to the outside of a pipeline for the length of the pipe. The fiber has the ability to sense strain/temperature of the pipeline and communicate that back to the utility		High accuracy. Once installed, relatively easy to maintain. Provides realtime strain monitoring. Particularly useful in areas with high seismic activity.	Difficult to install on existing pipelines. Requires extensive fiber optic communication system.
Strain Gauge	A device that monitors changes in strain due bending/movement of the pipe. The device uses a pattern of wire to translate the movement into a measureable electrical signal. Destructive Test using 3 strain gauges arranged in a triangle and drilling a hole in the center to detect strain direction.		Can detect variations in pipeline strain. Provides important information with regard to seismic activity and land movement	Only provides information at location where installed. Short life span. Difficult to maintain.

Source: GTI

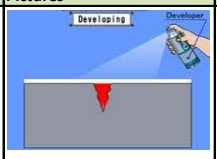
Figure 14: Remote Stress/Strain Analysis of Pipelines – Emerging

Emerging Remote Stress/Strain Analysis of pipeline					
Long-Term Condition Monitoring Techniques	Laser Reflectometry and Signal Processing	This proof of concept project is focused on developing a prototype sensor and laser emitter/detector system to allow the calculation of these stresses in a way that operators can use the system to identify threats and assess the risk to the impacted pipeline segment.	This is a new SMP project initiated during the fall of 2012, the projected completion date is the end of 2013.	Pipelines undergo a variety of stresses and strains which may arise due to internal gas pressure and normal operations or from pipe bending and movement due to soil settlement, thermal expansion, flooding, seismic activity, ROW construction or other superimposed stresses. When a bending moment or displacement occurs the stress may exceed the design safety margin of the system.	GTI Research Programs

Source: GTI

Figure 15: Nondestructive Examination and Analysis Methods – Commercial

EXAMPLES OF NON-DESTRUCTIVE EXAMINATION TECHNOLOGIES

Technology	Description	Pictures	Strengths	Weaknesses, Limits or Gaps
Liquid Penetrant Testing (LPT)	LPT, also called Penetrant Testing (PT) and Dye Penetrant Inspection (DPI) is a low-cost inspection method used to locate surface-breaking defects in all non-porous materials (metals and plastics, or ceramics). It is used to detect surface defects such as hairline cracks, surface porosity, leaks in new products, and fatigue cracks on in-service components.		This method is a simple, low cost defect detection technique that can be applied and analyzed in the field. The results of the test are instant and visible, and make for a swift repair or rework.	Only Surface detection
Magnetic Particle Testing (MT)	MT is a process for detecting surface and subsurface discontinuities in iron and steel pipes. The process puts a magnetic field into the pipe. The presence of a crack or surface discontinuity allows the particles to build up at the discontinuity and form an indication.		This method is a simple, low cost defect detection technique that can be applied and analyzed in the field. The results of the test are instant and visible, and make for a swift repair or rework.	Only Surface detection
Ultrasonic Testing (UT)	Pulse-waves with frequencies ranging from 0.1-15 MHz and occasionally up to 50 MHz are launched into materials to detect internal flaws or to characterize materials. The technique is also commonly used to determine the thickness of the test object, for example, to monitor pipe work corrosion.		This device allows for a spot check readout for measuring wall thickness and metal loss. Some devices have the ability to detect corrosion thicknesses and differentiate between internal and external characteristics.	single spot check only
External Guided wave	GUL Wavemaker/Teletest Service. Transmits Ultrasonic guided waves transversely along the pipe to locate corrosion spots and defects.		The device produces a 100% volumetric scan, and extends its sensing abilities axially. The external guided wave transducer can scan up to 400m length of pipe from a single scan location. Up to 36" diameter pipe and the line remains in service during the testing procedure.	early prototype. Transducer harness designed for specific diameters. Not keyhole accessible, needs exposed pipe.
Electro Magnetic Acoustic Transducer (EMAT)	EMAT technology utilizes varying magnetic fields to induce a signal into a pipe wall to measure wall thickness. Although similar to Ultrasonic testing, this methodology does not require a liquid couplant. Exploits properties of steel.		EMAT technology requires no couplant. The data captured includes wall thickness measurements, and wall loss. Works well on corroded surfaces and is a NACE certified method for SCC detection. It is capable of scanning large diameter pipes and available for external or internal inspection.	
Guided Wave	Magnetostrictive Sensor Guided-Wave (MsSR3030 instrument). (Acoustic frequency range up to ultrasonic)		Sensors are wrapped around the pipe like a ribbon and fitted to the appropriate diameter so there are no size dependancies. Data analysis software is ran on a PC. The user can detect limited pipe wall defects based on the pattern of feedback signals. Detection focus area extends in both directions from sensor.	Cannot distinguish coating flaws from wall defects.
Film / Digital / Computed traditional X-ray analysis	Provides a tried and true means for component integrity analysis. Capable of detecting internal and external defects with high resolution imagery. Devices have been manufactured for field work or laboratory analysis.		Designed to be portable for field use, and adaptable for different materials. The unit renders 3D images of scanned components allowing for easier defect identification. Narrow focal lengths. This is a standard inspection method found in pipe manufacturing houses, back office labs, and field-weld inspections..	automatic defect identification, or distinguished attribute detection. Radiation concerns. Intrinsic safety?

Source: GTI

Figure 16: Nondestructive Examination and Analysis Methods – Emerging

Emerging Non-Destructive Examination & Testing					
Radiographic Technology (RT)	RSD X-Ray	Use of X-ray Radiography Selective Detection technology to inspect and assess pipeline damage and welds. Feasibility test completed at GTI successfully demonstrating detection and identification of faults on metallic or PE pipe.	Technology needs to be commercialized and further tested for industry use before it can be adapted for field-use and pipeline application.	Provides capability to detect pipe dents, pits, punctures, weld imperfections and other weakened areas. Scans entire thickness of pipe. Possible ILI tool. Tested with COTS materials and instrumentation.	
Integrity Management	EMAT	EMAT technology and tools require further assessment and application-based testing to highlight girth-weld inspection capabilities and accurate crack length measurements. This technology is commercially available and used, but improvements are still needed.	Although technology has reached a stage of maturity, improvements to the capabilites of EMAT in its ability to detect SCC, hydrogen induced cracks, fatigue cracks, hook cracks, and a variety of other irregularities and defects is required.	EMAT technology offers couplant-less wall thickness measurements and anomaly detection of gaseous pipelines without purging or rigorous cleaning. This advancement may make EMAT ILI inspection one of the primary methods used to ensure a pipeline is Fit-For-Service.	
Obstacle Avoidance	Directional Electromagnetic Field Exploitation	HDD drill bit with an integrated sensor that can detect obstacles in and around the drill path. This prototype was first developed at GTI, where functionality was verified in a laboratory setting, however work remains to refine the technology for practical applications. Further development is needed to eliminate false positives, and a communication medium should be implemented.	Project updated last in 2008 with a final report. The technology has not been finalized for manufacture or application, and further development is necessary for practical use.	This technology would provide the operator with real-time obstacle information to reduce the chance for third party damage to buried utilities during Horizontal Directional Drilling.	http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=190

Source: GTI

Figure 17: Data Collection and Communication Technologies – Commercial

EXAMPLES OF DATA COLLECTION & COMMUNICATIONS TECHNOLOGIES				
Technology	**Description**	**Pictures**	**Strengths**	**Weaknesses, Limits or Gaps**
Geographical Information System	Use of a mapping system to keep records and maintain an accurate visual depiction of all pipelines in system. May follow certain models of data storage such as APDM and ICAM		Ability to quickly locate records and information on particular pieces of the pipeline.	Data entry options.
Microwave	Microwave communication relies on a Line-of-sight link between two base stations, capable of spanning great distances and providing reliable data communication.		quick deployment. Obstacle avoidance. Typical range is 30% farther than optical horizon. Point-to-multi-point supported	requires line of sight.
Cellular	Utilizing the growing wireless infrastructure of 3G cellular communication to monitor critical system data		An increasingly reliable medium of communication, cellular service offers fast data rates in remote locations. It's readily available in many areas, allowing for nearly transparent integration into your SCADA system.	inconsistent connection, coverage limitations
Phone Line	Dedicated phone line provides consistent and reliable communication for monitoring critical system data		Although not as expansive as cellular, a dedicated phone line offers reliable, direct connections to SCADA systems. Chances for data interception or alteration is low. The en route data can be encrypted for extra layers of protection.	expensive to install
Fiber Optic	Fiber optic cable buried along pipe or part of a separate infrastructure is capable of transferring high fidelity information over long distances. The connections are reliable, although your data is packaged with others on the same network.		Fiber channels offer communications capabilities with high bandwidth and integrity. A typical fiber infrastructure has infrequent, but regularly-spaced base stations or repeaters to transmit long distances.	expensive to install, usually with new installations
Human Machine Interface (HMI)	Human Machine Interface. System of protocols to allow human control of industrial machinery to maintain a widely compatible interface.		A term specific to the system, an HMI gives control of a system to more than just a single user, but rather to remote users as well. This is common in most SCADA systems.	

Source: GTI

Figure 18: Data Collection and Communication Technologies – Emerging

Emerging Data Collection & Communication Techniques					
Method	**Technology**	**Description**	**Path to Market**	**Gap Fulfilled**	**Reference**
Data Management	Advanced Bar Coding Tracking System with ASTM F2897-11	This method of assigning, storing, and managing asset information of buried pipelines and appurtances with digital records is the goal of this technology development.	This standard of desired data for pipelines, components and new installations will provide distributors with substantial records of their systems. This technology must be incorporated into new tools and made available to the installation crews of LDCs.	This technology is being developed so that pipelines, appurtances, labor, and maintenance schedules can be recorded to improve the safety of pipelines and improve the management of LDC crews and workers. It would address the issues related to the permanency and durability of the bar code markings, how frequently the markings should be made, how the various fittings and appurtenances should be marked and what type of marking techniques should be used.	GTI Research Programs
Data Integration	Geographic Information System (GIS)	A "living" data repository that comprehensively integrates all aspects of a company's work force, labor utilization, job identification and location, customer information, and asset tracking management into a relational system aimed at improving and streamlining the data acquisition and analysis components of organizational management.	Based on the interviews conducted during Task 2, the use of a GIS varied by operator from the simple use for creating maps to more sophisticated data utilization. The majority noted the need for improvements or upgrades to existing systems along with the need for an integrated solution that would allow the single entry of information resulting in immediate availability across the enterprise systems.	GIS fulfills the need for improvements or upgrades to existing systems, along with the need for an integrated solution that would allow the single entry of information resulting in immediate availability across the enterprise systems.	
Wide Area Communication	Mobile Mesh Networking Technology	Data can be transferred over Bluetooth, RFID, Zigbee, Wifi Networks, and other forms of low power, robust, secure layer-based radio waves collectively forming data links between nodes. These methods are defined by IEEE industry standards which ensure cross-platform compatibility with any classified device.	Any path to market with short-range radio waves will be an adaptation of an existing technology with the amended functionality of wireless communication to a centralized data center.	These devices can be used to monitor large areas of land with minimal energy and resources. This makes the technology very attractive for integrity management of pipelines.	
Wide Area Communication	Long Range RFID-Based Pipeline Communication System	A GTI-developed technology that utilizes a steel pipeline to carry digital information originating from sensor-node units (buried adjacent to the pipeline at strategically selected locations) to a centralized receiver. This sensor-node can monitor pipe-to-soil potential, ambient temperature, or other critical attributes common to the maintenance of the pipeline and prevention of corrosion.	Project has completed laboratory and initial field proof-of-concept testing. A patent is pending approval. The technology is currently in the range testing stage of development, verifying two-way communication on lengths of pipe greater than 300 ft between receiver and node-sensor.	This technology eliminates the need for extraneous wireless data links and costly infrastructure to capture highly critical pipeline data from remote locations. This type of long range monitoring is desired by pipeline operators to detect and locate potentially hazardous situations, and provide immediate help. Also it uses the infrastructure already in place, keeping costs low for highly valuable information.	GTI Research Programs

Source: GTI

Figure 19: Risk Modeling and Incident Prediction Tools – Commercial

EXAMPLES OF RISK MODELING AND INCIDENT PREDICTION TECHNOLOGIES				
Technology	**Description**	**Pictures**	**Strengths**	**Weaknesses, Limits or Gaps**
Use of Real Time Transient Model software	The model simulates transient flows in the pipeline. The application software generates a real-time transient hydraulic model using field input from meters at strategic receipt and delivery locations, referred to as software boundary conditions. Fluid dynamic characteristic values are modeled throughout the pipeline, even during system transients. The RTTM software compares the measured data for a segment of pipeline with its corresponding predicted values.		Able to detect 1 percent leaks in seconds. Leak flow rate and leak location can be estimated. Leaks can be detected for shut in, slack line, and transient conditions.	The method is difficult to learn and use. The model must be customized and tuned to each unique pipeline configuration. Implementation, testing, and maintenance are difficult. Costs are very high.
Statistical Analysis	Statistical analysis is performed on a measured pressure to discern a decrease in the mean value over a threshold. To reduce the frequency of false alarms, more sophisticated statistical analysis methods use pressure and/or flow at multiple locations. Leak alarm generation is based on a set of consistent patterns of relative changes of the mean data at different locations.		Able to detect 1 percent leaks in seconds to minutes. Leaks can be detected for shut in and transient conditions. False alarms are less frequent. Leak location can be estimated. The method is easy to use. Retrofitting and maintenance are easy. The method is more robust.	Existing leaks and leaks in slack line conditions cannot be detected. Leak volume difficult to estimate. Implementation and testing are difficult. Costs are high.
Digital Signal Analysis	The response of the pressure, flow and other sensors to a known impulse change in flow is measured and digital signal processing on these normal operation responses is used to recognize the changes in the responses of these sensors when a leak occurs.		Able to detect 1 percent leaks in seconds to minutes. Leaks can be detected for shut in and transient conditions. False alarms are less frequent. Leak location can be estimated. Maintenance is easy.	Existing leaks and leaks in slack line conditions cannot be detected. Leak volume difficult to estimate. Implementation and testing are difficult. Costs are high.

Source: GTI

Figure 20: Risk Modeling and Incident Prediction Tools – Emerging

Emerging Risk Modeling and Incident Prediction Tools					
Method	**Technology**	**Description**	**Path to Market**	**Gap Fulfilled**	**Reference**
Software Applications/SCADA	DRAM - Dynamic Risk Analysis and Management	A risk model that integrates GIS spatial data with various risk factors to create a probabilistic method of predicting risk.	Widespread adoption of this technology/methodology into pre-existing GIS markets will not happen without dedicated integration into these systems by their manufacturer.	Models potentially hazardous processes in space and time. Improves decision-making for balancing of risk, financial, and sustainability aspects of major capital investments – shale plays, carbon capture, and others. It can do all this computation from within a GIS System.	
Modeling and data harvesting	Stress Corrosion Cracking	PRCI has a research program to examine technologies and guidelines for detection and characterization; models for assessing data and predicting failure pressures, mitigation and safe field operations (grinding limits)	Research	Analysis of stress corrosion cracks, crack growth detemination, NDE technology validation	PRCI
	Mechanical Damage	PRCI has several research programs to characterize and evaluate the impacts of mechanical damage to pipe, compiling testing results into a database to improve MD models	Research	The program develops full-scale testing database for MD features to be used for improving MD models. This would quantify ILI performance for cracks/dents/gouges	PRCI
Modeling and data harvesting	Stress Corrosion Cracking Analysis - Destructive Testing	A stress/fatigue measurement device will be used to capture material characteristics with pressurized hydrogen product. crack prediction models and associated stages will be defined and used to better identify SCC and maintenance schedules. Effect of Microstructure of Pipeline Steels on Ductility and Fatigue Properties in High Pressure Hydrogen Atmosphere	Project ended in 2011. This technology will be used to support industry consensus standards for hydrogen transport via pipeline.	Analysis of the fatigue and embrittlement of steel with high pressure hydrogen to determine crack characteristics and growth rates to better predict pipe condition and wear.	http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=324

Source: GTI

Figure 21: Tools, Techniques and Data Analysis Methods in IMP's – Commercial

EXAMPLES OF TOOLS, TECHNIQUES, AND DATA ANALYSIS METHODS IN INTEGRITY MANAGEMENT PROGRAMS TECHNOLOGIES				
Technology	**Description**	**Pictures**	**Strengths**	**Weaknesses, Limits or Gaps**
FRASTA - Fracture Surface Topography Analysis	FRASTA examines the surface topography of a crack to reconstruct the cause of damage, determine effects of pressurization, and ultimately model the situation to predict pipeline failure.		Can help determine the cause of a crack. Will help determine life expectancy of the pipeline and set inspection intervals.	Will not identify where cracks are.
Quantitative Polymerase Chain Reaction	A PCR process that surpasses shortcomings of conventional methods by targeting the specific corrosion causing bacteria and quantifies their composition and growth characteristics.		Capable of analyzing a variety of sample consistencies. Quantifiable results. Early as 24 hour turn-around. Doesn't require living/active samples. Additional Live/Dead differentiation test. Spore detection. More accurate and less conservative readings than MPN tests. Tests against the 10 most influential prokaryotes.	required minimum size sample from pipe of interest. Opportunity to increase the number of interrogated prokaryotes.

Source: GTI

Figure 22: Tools, Techniques and Data Analysis Methods in IMP's – Emerging

Emerging Tools, Techniques and Data Analysis Methods in IM Programs					
Method	**Technology**	**Description**	**Path to Market**	**Gap Fulfilled**	**Reference**
Management Practice	Internal Inspection Optimization	This is an OTD sponsored project to analyze the internal inspection methods to identify gaps/areas for improvements.	Phase 1 is complete, Phase 2 is underway. The investigative efforts of this project are being provided by GTI for OTD.	This project will identify gaps and improvements to internal inpsection technologies that will enhance the performance and results for operators.	GTI Research Programs

Source: GTI

Figure 23: Detection of Pipeline Leaks and Ruptures – Commercial

EXAMPLES OF DETECTION OF PIPELINE LEAKS AND RUPTURES TECHNOLOGIES

Technology	Description	Pictures	Strengths	Weaknesses, Limits or Gaps
Flame Ionization Detectors (FID)	Flame Ionization Detectors - Detects the presence of VOCs that indicate the level of methane gas in the area. This model is portable and applicable for leak detection, HAZMAT areas, Leak Detection and Repair (LDAR), etc.		portable, wide VOC range. Data storage. Intrinsically safe. Bluetooth. 70 hour fuel cell life. Capable of extreme concetration levels. Rentable	Expensive. Degree of accuracy?
Helicopter mounted laser leak detection	A tool that samples the air above the pipeline and uses laser technology to detect methane. The tool is attached to the base of a helicopter as it flies the pipeline path.		Can detect methane to 1 part per million. Real time detection as helicopter flies over pipeline.	Only can provide approximate area of leak. Unable to pinpoint leak. Relatively expensive to fly helicopter.
Wavelength-Scanned Cavity Ringdown Spectroscopy (WS-CRDS)	Picarro G1301 is a real-time (10hz) ambient gas analyzer that can monitor precise (ppbv) amounts of CO_2/CH_4 and (ppmv) H_20.		Field-ready. High performance, high resolution with low calibration drift. Repeated field success.	Expensive. Requires a PC to operate.
LIDAR	A helicopter equipped with a fly-by methane leak detector using infrared laser differentiation to pinpoint natural gas plumes from hundred of feet away provides a safer and quicker means to locate gas leaks.		Faster, Safer, more accurate than conventional walked/driven surveys. Takes photographs of the area being scanned and with the assistance of a PC, overlays the spots that have been indicated as having a higher concentration of methane.	5+ year old technology.
Optical-Based Technologies	Point or open-path monitoring of combustible gases using IR gas detectors or catalytic bead detectors.		IR detectors are more accurate and require less calibration than a catalytic bead-based detector. They do not require the presence of oxygen. An Open-path detector can increase the sampled gas to accommodate large flow areas or storage containers	Expensive. Can only detect Hydrocarbon, or other IR absorbing compound. Limited operating temperatures and humidity.
Pressure/Flow Monitoring	Rapid depressurization, rapid inflow increase, rapid outflow decrease, and rapid increase in the difference between inflow and outflow are associated with the onset of a leak.		Leaks can be detected in shut in conditions. Can estimate the volume and location of large leaks. Retrofitting and maintenance are easy. Able to detect 5 percent leak in minutes.	Small leaks, existing leaks, and leaks during slack line conditions can not be detected. Implementation and testing are not easy. The method is not easy to learn and use. False alarms are frequent during transient conditions. Method is less robust than others.
Metering	Measurement of the difference in incoming and outgoing delivery volumes provides utilities with important usage characteristics for configuring an IMP system and identifying malfunctions.		Easy to use. Testing and maintenance is easy. Costs are relatively low. Detect less than 5% leak in minutes to hours.	Leaks cannot be detected in shut in or slack line conditions. Small leaks may have long detection times. Location of leak cannot be determined.
Pressure/Temperature/Density sensitometer sensors	In this method, leak flow equals inlet flow minus the outlet flow minus the rate of change in line pack. When the leak flow exceeds a specified threshold, a warning is displayed and an alarm sounds. Volume imbalance is typically monitored over a number of time periods to detect commodity releases of different sizes		Existing leaks and leaks for shut in and transient conditions can be detected. Able to detect 1% leaks in minutes. Leak detection can be used during transient conditions with less frequent false alarms. The method is adaptable to any pipeline configuration.	Leaks can not be detected during slack line conditions. Implementation, retrofitting, and maintenance are not easy. The location of a leak cannot be determined. High Cost.
Use of RTTM software	The model simulates transient flows in the pipeline. The application software generates a real-time transient hydraulic model using field input from meters at strategic receipt and delivery locations, referred to as software boundary conditions.		Able to detect 1 percent leaks in seconds. Leak flow rate and leak location can be estimated. Leaks can be detected for shut in, slack line, and transient conditions.	The method is difficult to learn and use. The model must be customized and tuned to each unique pipeline configuration. Implementation, testing, and maintenance are difficult. Costs are very high.

Source: GTI

EXAMPLES OF DETECTION OF PIPELINE LEAKS AND RUPTURES TECHNOLOGIES - Continued				
Technology	**Description**	**Pictures**	**Strengths**	**Weaknesses, Limits or Gaps**
Statistical Analysis	Statistical analysis is performed on a measured pressure to discern a decrease in the mean value over a threshold. To reduce the frequency of false alarms, more sophisticated statistical analysis methods use pressure and/or flow at multiple locations. Leak alarm generation is based on a set of consistent patterns of relative changes of the mean data at different locations.		Able to detect 1 percent leaks in seconds to minutes. Leaks can be detected for shut in and transient conditions. False alarms are less frequent. Leak location can be estimated. The method is easy to use. Retrofitting and maintenance are easy. The method is more robust.	Existing leaks and leaks in slack line conditions cannot be detected. Leak volume difficult to estimate. Implementation and testing are difficult. Costs are high.
Digital Signal Analysis	The response of the pressure, flow and other sensors to a known impulse change in flow is measured and digital signal processing on these normal operation responses is used to recognize the changes in the responses of these sensors when a leak occurs.		Able to detect 1 percent leaks in seconds to minutes. Leaks can be detected for shut in and transient conditions. False alarms are less frequent. Leak location can be estimated. Maintenance is easy.	Existing leaks and leaks in slack line conditions cannot be detected. Leak volume difficult to estimate. Implementation and testing are difficult. Costs are high.

Source: GTI

Figure 24: Detection of Pipeline Leaks and Ruptures – Emerging

Emerging Detection of Pipeline Leaks and Ruptures					
Method	**Technology**	**Description**	**Path to Market**	**Gap Fulfilled**	**Reference**
Leak Detection	Fiber optic	Asel-Tech has developed a fiber optic communication network that relays information from distributed acoustic monitoring devices along the ROW to detect leaks and notify the proper authorities. The fiber between nodes plays a role in detection, and, with advanced neural network processing, can minimize false positives.	A fully developed and commercialized monitoring and reporting system that is awaiting installment and assessment by utility companies to promote more widespread use.	This technology aims to eliminate the need to manually survey pipelines for signs of leaks by burying a permanent monitoring system adjacent to the pipeline.	http://www.asel-tech.com/marc-one.html
Leak Detection	Hydrostatic Leak Test	Alternative Materials and Methods for Detecting Small Seeps and Leaks During Field Hydrostatic Testing	Current PRCI project	Improvement to hydrostatic pressure test leak detection.	PRCI
Leak Detection	Aerial Surveillance	PRCI RAM (Right of Way Automated Monitoring) program. PRCI has tested two separate field test trials of aerial inspection sensor technologies for detecting encroachment of machinery threats and natural gas leaks from energy transmission pipelines	Need to validate test results and make any necessary corrections to improve results to finalize prototype.	Aerial leak survey	PRCI
Leak Detection	Smart Pipeline Network - Pipe & Repair Sensor System	A network of sensors contributing to a real-time pipeline monitoring effort to detect intrusions, detect and pinpoint leaks, and relay critical pipeline health information.	This research is just getting underway and being administered by PHMSA with the investigative efforts being addressed by Odyssian Technology LLC. The proposed completion date is the first quarter of 2013.	A technology like this would promote a living pipeline with the ability to alert operators of poor pipe conditions and potentially hazardous situations; putting electronics to work to make the transfer of energy safer.	

Source: GTI

Figure 25: Methods for System Shutdown – Commercial

EXAMPLES OF AUTOMATED, SEMI-AUTOMATED AND MANUAL SHUTDOWN TECHNOLOGIES				
Technology	**Description**	**Pictures**	**Strengths**	**Weaknesses, Limits or Gaps**
Valve	A valve that is a component of a pipeline that is meant to stop the flow of gas into certain parts of the transmission network. These valves may be connected to a SCADA system offering remote control. Some valves require manual reopening if in response to an alarm.		It allows for control of the pipeline without putting people's lives in danger. A critical component to contain a leak or rupture. Useful for product transfer points. Easy integration into SCADA systems.	More expensive than a manually operated valve. Require communication capability.
Check Valve	A check valve automatically adjusts its status based on the flow rate. If the rate drops, the valve will close in an effort to prevent backflow in the system. They are frequently installed at compressor stations where line pressure and the risk for improper flow direction increases.		Prevents gas from flowing in the undesired direction. It is the first responder to a drop in pressure and does not require user interaction or SCADA control.	current state made available to SCADA? Not adjustable minimum "on" pressure
AGA 12 Encryption (2006)	GTI developed standard for encrypting messages relayed by RTU's and SCADA equipment to prevent cyber hacking of critical pipeline control systems. This is an option on top of standard protocols.		This encryption method is robust and effective against data interception, hacking, and data manipulation.	Old technology, designed for modem speeds. Not widely used.
RTU - Bristol's ControlWave, Allen Bradley's DataSite, Fisher's ROC-800	A low power remote unit that provides system critical information to the SCADA system. The SCADA system then sends commands to the RTU's based on the interpretation of this data. An RTU will house power supplies, DAQ cards, system controllers, remote user terminals, and a variety of pipeline component interfaces.		An RTU is a robust, rugged, expandable, scalable system controller with standardized communication protocols to fit any system's requirements. Outside connectivity over ethernet provides security and speed. Compatible with HART and MODBUS communication systems.	integration into GIS
MODBUS. HART. FIELDBUS.	Standardized communication protocol that offers expandability and security. Mesh network and IP/TCP addressable. Used by the RTU to communicate with the controllable peripherals (valves, pressure sensors, etc.) Digital signal that is superimposed on the analog sensor reading.		HART is the community leader in sensor and SCADA array communications protocols. Both are widely adopted and standardized, and provide the capacity to expand SCADA networks.	Many other protocol options are available.

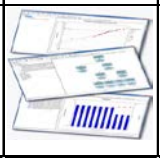
Source: GTI

Figure 26: Methods for System Shutdown – Emerging

Emerging Automated-Semi-Automated and Manual Methods of Shut-down					
Method	**Technology**	**Description**	**Path to Market**	**Gap Fulfilled**	**Reference**
	Differential Pressure Vacuum Cleaning Pig	This inline pipe cleaning tool is designed specifically to remove black powder that has built up on the inner wall of a pipeline. It uses a collaboration of magnetic brushes, polyurethane sealing disks, vacuum tubes and a specially designed centered bypass inlet to create a pressure differential that provides optimum powder collection as the unit travels a length of pipe. Significant design updates have allowed for very successful test runs collecting and removing substantial amounts of black powder during the entire run of a pipe, reaching 170 km.	The tool works best on pipes with more black powder deposits. Maintaining a differential pressure is difficult as conditions can change throughout a pipe run. This technology is closing the gap in difficult pipe cleaning operations with its advanced methodologies, however further development can make this a more adoptable solution to one of the industry's more critical problems.	The Rosen black powder cleaning tool can collect and remove large quantities of dust deposited on the pipe wall. Its high capacity and sustainable differential pressure make it capable of cleaning expansive lengths of pipes, upwards of 170km. It also rotates continuously to prevent any one side from excessive strain and ensures circumferential suction.	http://www.roseninspection.net/MA/papers/PPIM_2012_BlackPowder_Paper.pdf
	Double Block and Bleed Temporary Isolation Pig. BICEP and Techno Plug.	A double block-and-bleed isolator is an inline tool designed for temporary flow blockage while work is being completed downstream. The device seals the circumference of the inner wall at two isolation points equipped with a bleed off vent within the void between them. The pressure in the void is monitored. This prevents any one failure from negating the isolation and allows for the bleed off of building pressure to a safe area.	Although the double-block-and-bleed method has reached a level of industry adoption, automating the process with	This tool is equipped with many fail safe features that make it better than previous methods for isolation. A metal seal ring that has the same diameter as the ID of the pipe is used to create the seal. Rubber material is used to complete a seal in such a way that the line pressure actually aids in the sealing process. The BISEP isolator is inserted through a hot tap, permitting temporary or permanent installations.	http://www.statsgroup.com/NewsArchive/PipelineIsolationDBB.html
Remote Controlled Valve	Transmission EZ Valve	This is a proof of concept project to assess the capability of installing a permanent cut-in valve on a live transmission gas line. The current EZ valve system is used in the water industry and operates at pressures up to 100 psig. A concept to develop a valve similar to the EZ valve used in the water industry but designed for the higher pressures found in the gas industry was developed in response to the challenges identified with installing automatic shut-off valves and remote control valves at the PHMSA R&D Forum held this past July, 2012. The work will include the consideration of all material issues, geometric constraints and operational needs.	This is a new project initiated by SMP during the fall of 2012, the planned completion date is the second quarter of 2014. It is recommended that the CEC participate in this SMP project to develop the capability of installing a permanent cut-in valve on a live transmission pipeline.	A valve that is easier to install, require less operator input and hassle, and is remotely operated is requested from the PHMSA R&D forum held this past July, 2012. The migration of the EZ valve to high pressure can close this gap.	

Source: GTI

Figure 27: System Modeling of Incident Responses and Shutdown – Commercial

EXAMPLES OF SYSTEM MODELING OF INCIDENT RESPONSES & SHUTDOWN TECHNOLOGIES				
Technology	**Description**	**Pictures**	**Strengths**	**Weaknesses, Limits or Gaps**
System Modeling	Transient liquid flow simulator used throughout the industry to assist in the design of pipeline systems.		Through a few iterations, an analyst is capable of modeling heat transfer, pipe flow, gas composition, corrosion, leaks, compressor start-up and shut-down sequences, regulator setpoint changes and upset conditions, regulators, valves, headers and heat exchangers to better predict how a given input will affect the output.	Direct integration to active GIS? SCADA system?
Isograph's Reliability Workbench	A hierarchy of cause-and-effect clauses that represent all possible scenarios for a given system to better prepare for and predict inspection, repair, maintenance schedules, and infrastructure lifecycles.		This system incorporates a comprehensive list of data into a preconfigured algorithm that interprets terabytes of data to improve the integrity management system through better risk assessment, component lifetime predictions, and worker	Expensive. Learning curve.

Source: GTI

Figure 28: ROW Encroachment and Excavation Damage Prevention – Emerging

Emerging Right-of-Way Encroachment and Excavation Damage Prevention					
Method	**Technology**	**Description**	**Path to Market**	**Gap Fulfilled**	**Reference**
Pipe Locating	Acoustic ground penetration radar	Hand-held Acoustic Pipe Locator injects an acoustic signal directly into the soil. The reflected signal is analyzed in real-time to provide information on buried pipe.	As of 2009, this technology is in its developmental stage. Initial research and prototype were successfully completed. Proposed work for 2010 included capturing statistical analysis from field tests and generate system emulations.	This technology has led to the development of a bench tested prototype capable of locating and identifying buried utilities.	BG Group
Plastic Pipe Locating	Acoustic signal manipulation	A buried pipeline locator that injects acoustic signals into the pipe, either steel or PE, that resonates a given distance. This signal is detectable above ground and the operator can mark the location of the utility.	The last update from this project was in 2011 with a final report. This technology has been field-verified and is ready to be commercialized and packaged.	Device to locate buried PE and steel pipe prior to digging operations to prevent third party damage	http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=365
Utility Locating	GPR	Development of a large scale, multi-sensor, magnetic sensor grid for underground utility mapping provides a means to quickly and efficiently scan a large area of ground with penetration down to 10 feet below the surface.	This technology was licensed in 2004 to Witten Technologies. This company was liquidated in 2009.	A vehicle-mounted unit can cover more ground with less fatigue on the user, minimize job time, and reduce costs.	http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=109
ROW monitoring	Acoustic/seismic sensors	Infrasonic Frequency Seismic Sensor System for Pipeline Integrity Management (PIGPEN). This device, although the project ended in 2005, provides a unique seismic (vibration-based) way to detect movement, and its signatures, near a pipeline to prevent damage. Each unit monitors up to 1km of pipeline. PIGPEN technology is an adaptive pipeline monitoring system that detects unauthorized intrusions with a autonomous learning algorithm that promises to minimize false alarms.	This is an old project and either it has been absolved, or the acoustic monitoring devices out there now already use this technology. GTI has looked into this as well detecting seismic activity at interval locations. A renewed effort promoted this technology as an active project with a 2014 end date. Reporting half-way through development indicates a focus on determining the learning algorithms and adapting sensor's responses to physical events.	New tools to monitor the ROW are necessary as third-party damage is still the leading cause of pipeline failures.	http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=135 http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=366

Source: GTI