PIPELINE TECHNOLOGY PROFILE

Technologies for Improved Safety, Reliability and Integrity of the Nation's Natural Gas and Liquid Pipelines

This "Pipeline Technology Profile" presents two matrices in a simplified format using lay terms to provide an overview of technologies currently in use and those under development to test/inspect pipelines with respect to safety, reliability and integrity. These technologies generally fit into one or more of three basic areas of focus:

Damage Prevention

Damage by 3rd party contact or intrusion or by environmental causes can cause unexpected harm to buried pipe, increasing the risk of gas or liquid losses or incidents. Improved non-destructive and non-intrusive monitoring technologies to detect 3rd party damage or environmental impacts when they occur will enable improved and more frequent monitoring detect damage in its earliest stages.

Improved Materials

Pipeline buried in the ground is subject to a broad range of stress and damage factors. Failures are difficult to detect, locate and mitigate in their early stages. Improved materials will help to extend the integrity and lifetime of installed pipelines.

Enhanced Operations

Regardless of the quality of the materials, pipeline equipment will degrade over time and repairs will be necessary for successful safety and integrity maintenance. Improved technologies for operating, controlling and monitoring the safety and integrity of pipelines will ensure safety and lower operation and maintenance costs.

The first matrix, "EXISTING TECHNOLOGIES PROFILE", was developed by the Association of Oil Pipe Lines (AOPL). It is a summary of the current state-of-the-art of pipeline safety-related tools and test procedures. The identified technologies are tools used to address one or more of the three areas of focus above. (We apologize for the small print needed to format the matrix on a single page.)

The second matrix, "PIPELINE TECHNOLOGY DEVELOPMENT PROFILE", maps the R&D activities and needs related to the categories above, along with a section on emerging R&D needs for Arctic and offshore applications. We have categorized the technologies under development into one of the three areas of focus. The profile includes information provided by the Gas Technology Institute (GTI), the Pipeline Research Council International (PRCI), AOPL, the Department of Energy and the Minerals Management Service within the Department of Interior with respect to specific R&D activities funded by these federal agencies. We thank DOE, MMS and AOPL for their assistance. You may get additional information from their web sites.

We have focused on technologies for improved safety, reliability and integrity and have omitted technologies that are primarily self-serving to the industry such as those directed to cost-effective construction and enhanced throughput.

This is a living document and will be supplemented by information at and after the Workshop. We would appreciate any comments or additions you may have in advance of the Workshop.

EXISTING TECHNOLOGIES PROFILE
For Safety, Integrity and Reliability of the Nation's Natural Gas and Liquid Pipelines

	Tool/Procedure	Description of Tool/Test Procedure	What is Measured	Results	Strengths	Weaknesses	Regulations	Cost	Comments
I	**Hydrostatic Testing**								
II	**Maintenance Pigging**								
III	**Smart Pigs**								
E	Crack Inspection Pigs	Relatively new electronic internal pipeline inspection pigs that look for axially oriented cracks originating from the external wall of the pipe. The pig is inserted into the pipeline and propelled with either the shipped product or water. Upon removal, the data is sent to an interpretation center for analysis. Analysis takes a minimum of 2 months before recommendations are made.	Ultrasound is transmitted in the pipe wall in the circumferential direction. Cracks reflect the ultrasound back to the transmitter.	The pigs locate axial cracks in the pipe body or in the long seam weld.	These devices provide the only way to find cracks in pipelines other than hydrotesting. The tools are getting better and have some ability to size cracks. This will allow operators to repair cracks before they would fail a hydrotest. Liquid operators have successfully used this technology to find cracks in the long seam weld.	These tools are relatively new to the market. Some have trouble differentiating benign inclusions from actual cracks, requiring excavations of many locations that contain no cracks. The best tool requires the tool to be run in a liquid and thus cannot be run in a gas pipeline without great expense. Tools are typically longer than MFL pigs and require longer traps.	None	Costs are reported to be $10,000+ per mile	
F	Mechanical Damage Pigging	No commercial tool exists that can reliably detect 3rd party damage to pipelines. Ongoing R&D sponsored by the U.S. DOT and Gas Research Institute (GRI) shows promise at detecting the stresses and plastic deformation associated with this type of damage.	High magnetic fields used in MFL pigs are combined with lower strength magnetic fields to look for stress and cold-working patterns found in mechanical damage.	Experimental results at the pipeline simulation facility look very promising. The signal levels are still relatively small but the characteristics of the signal are unique and should allow unique classification of mechanical damage.	Allows a signal that is unique to mechanical damage to be measured from in-line inspection pigs.	Technology has not been proven in operating pipelines.	None	Not Commercial yet.	
IV	**Pipeline Coating**								
B	Develop New Coating Evaluation Testing (Continuing Research)	Proper coating selection remains one of the most important decisions for construction of a new pipeline, and this decision will significantly affect the life of the pipeline. The GRI/PRCI Corrosion Group has a number of coating projects either underway or getting underway which will benefit the Industry: □ Cathodic disbondment under realistic conditions □ Performance of blistered Fusion Bonded Epoxy □ Hi-Temp performance of existing coatings □ Coating Requirements for Horizontal Directional Drilling □ Entire surface inspection of coatings at coating mills □ Thermite weld repair in keyholes	The industry needs a means to predict coating performance for a given set of circumstances, including temperature, soil conditions, installation techniques, and ease of repair.	Knowledge of how coating will perform under certain conditions. This will allow the operator to make more economical decisions on both new construction and operating pipelines.	External Corrosion and Stress Corrosion Cracking problems are non-existent in areas where the coatings are well bonded, and it is protecting the pipe steel from the environment. Proper selection of new coatings and proper operation of pipelines with older coatings can help lengthen life of pipeline asset.	Coatings all have limits. It is better to understand the limits to avoid operation problems. It will be impractical to have a single coat perform the best in all cases. It should be expected to find problems with newer coatings used today.	Required by DOT to have protective coatings on all lines constructed today which will be buried or submerged. (49 CFR 195.238)	Low	
V	**Cathodic Protection**								
H	Buried Coupons (Recent Research)	Small buried metal coupons of a specific size, with wire leads to surface, are buried in the same vicinity of the pipeline at the bottom on an open non-conducting tube (PVC). The tube is filled with dirt, and the coupon is connected to pipeline via test lead connection, and is exposed to the pipelines cathodic protection system. The Pipe-to-Soil Potential of the coupon is recorded through the tube from the surface (tube minimized IR-error).	The Pipe-to-Soil measurement of the coupon indicates whether the cathodic protection is capable of protecting an anomaly of that size. The coupon also becomes polarized to a potential very similar to the pipeline's potential. Coupons also allow Instant-Off readings of coupon without interrupting the current sources.	An accurate estimation of the Pipe-to-Soil Potential of the pipeline.	Both "On", and "Instant Off Readings" can be taken very easily, without the costly interruption of numerous current sources. This method may be used in areas where it is impractical to interrupt current sources, such as pipelines protected with sacrificial anodes, or congested areas. Coupons also may not be affected by normal problems such as long line currents during interruption, telluric currents, AC induced voltage, and interference. Coupons may also be used for special testing of problem areas.	Buried Coupon installations will require excavation for installation. Buried Coupons must have a test lead at burial site, for measurements, and also connecting to the pipeline.	Required by DOT to have sufficient voltage readings to verify adequate cathodic protection per NACE Standards (49 CFR195.416) (Note – coupon readings cannot be substituted for pipe to soil potentials.	Low	Procedure used in Many countries, but starting to be used in US more frequently.
VI	**SCADA**								
D	Real Time Damage Monitoring	Sensors are placed on the pipeline to monitor contact to the pipeline from backhoes and other heavy construction equipment in real time.	Very low frequency acoustic signals are generated through contact with a pipeline. These propagate in the product for some distance down the pipeline.	Experiments on a few pipelines show the method can work for distances up to several miles from the sensors placed on gas pipelines.	Allows detection of contact with the pipeline that may prevent some delayed mechanical damage failures.	This technique has not been tested in liquid lines and testing in gas pipelines is limited. The technology is not commercially available.	None	Not Commercial yet.	
VII	**Right-of-Way Monitoring**								
I	Satellite Surveillance	There is a regulatory requirement to patrol the rights of way. Satellite surveillance offers new methods to do this. While optical satellite surveillance is not a new technology, the level of resolution has improved. Research is developing technology towards using radar surveillance to detect ground movement, infrared to detect gas lost, and optical for ROW monitoring of activity.	Depending on the satellite the right-of-way can be monitored for excavation, proximity of heavy equipment, house-counts, leak detection, and ground movement.	Knowledge of encroachments and construction activities along the right-of-way and possible leaks plus earth movement from subsidence, land & mud slides, liquefaction	Covers the right-of-way quickly and efficiently. The operator is able to see their right-of-way surface and activity easily in remote and suburban areas. This can be used in GIS to identify and track High Consequence Areas and Unusually Sensitive Areas as well as dwellings and other structures	The technologies are most cost effective, but not commercially available yet.	The operator of a pipeline is required to observe the Right-of-way at intervals not exceeding 3 weeks, but at least 26 times a year (49 CFR Part 195.412(a)).	Low	These technologies are proven and most are close to commercialization
VIII	**One Call**								
IX	**Internal Corrosion Control**								
F	Environmentally Benign Biocides	GRI is presently working on development of an environmentally benign biocide. The biocide can be placed in pipeline facilities to control biocide colonization and corrosion	The effectiveness of the biocide, along with the ability not to impede any other process in the pipeline. The disposal of biocide should cause no problems	Biocide that can be used in environmentally sensitive areas, and disposed of easily.	Easy disposal – Environmentally friendly May have applications outside of the industry	Working towards patent at this time. Will need a partner in sales and development. Need to check yet for compatibility with other process	The operator of a pipeline is not to transport corrosive hazardous liquids, unless he takes adequate steps to mitigate the corrosion. (49 CFR Part 195.418)		
X	**Overpressure Protection**								
XI	**Materials**								
A	Improved Methods for Assessing the Remaining Strength of Corroded Pipe.	During smart pigging or in-service inspections, corrosion is often found. The operator must assess the remaining strength to determine what, if any repairs are needed. To date, both the R-Streng and B-31 G formulas are conservative, and cannot estimate the interaction of corrosion pits	Corrosion pits are measured for depth, and length, to determine the remaining strength of the pipe. The research is considering which available calculation tools used will give the most accurate answer, and when to use each tool.	A much less conservative tool to calculate the remaining strength of corroded steel. The tool would also consider interaction of near-by pits.	Less conservative calculations for the remaining strength would reduce the number of interruptions on pipelines for repairs, reduce product loss experienced during repairs, and reduce inefficiency.	Measurement of pits will need to be exact, and may require more training, or development of better measuring tools. Need to do a good job of mitigating future corrosion in these areas.	Required by DOT to repair pipe by B-31 G or R-Streng (49 CFR 195.416 (h))	Low	
B	Influence of Higher Usage Factors on Structural Integrity for Grades X70 and Above	Higher Grade Steels are now being used on pipelines. There are savings involved from the production through the construction. Some regulatory bodies have increased the allowed design stress to raise from .72 to .80. The effect of higher design stress on high strength steels should be investigated.	Work will study the life cycle cost savings by using the .80 design factor. Work will also look at strain hardening rate and yield to tensile ratio, fabrication issues, mechanical damage, and others	Guidelines for using the higher grade pipe at a higher design factor	The use of higher grade pipe operating at a higher design factor can significantly reduce the construction cost of a new line	There are many unanswered questions at this time. Studies must be done to develop proper operating procedures to take advantage of this	49CFR192.105(a) and 49CFR195.106(a) still restrict the design factor to 0.72. However other regulatory agencies have allowed the 0.8 design factor, such as the DNV rules for submarine pipeline, and the new ISO standard. The UK Authority allowed the higher usage factor in the North Sea gas line constructed in 1996	Low	

PIPELINE TECHNOLOGY DEVELOPMENT PROFILE

R&D for Improved Safety, Reliability and Integrity of the Nation's Natural Gas and Hazardous Liquid Pipelines

Areas of Focus	R&D Issues	Background	Near-Term R&D (0-3 years delivery)	"Next Generation" R&D
Improved Material Performance: Pipeline buried in the ground is subject to a broad range of stress and damage factors. Failures are difficult to detect, locate and mitigate in their early stages. Improved materials will help to extend the integrity and lifetime of installed pipelines.	▪ **Damage and defect resistance:** Damage to, and defects in, pipeline materials may result from 3rd party contact, material fatigue or stresses in the wall of the pipe, or from long-term impacts of environmental factors such as moisture and soil movement. Better understanding of how damage or defects propagate, and the ability to control that propagation, will extend pipeline life and lower maintenance costs.	▪ Industry has well-developed models of varying degrees of sophistication that predict impacts of corrosion. ▪ Models for predicting impacts of mechanical damage, primarily 3rd party contact, exist, but need improvements in application. ▪ Well-established models for propagation of single cracks, for both static and fatigue loading. ▪ Additional validation needed of models for multiple cracks or crack and corrosion combinations.	▪ Guidelines and software to assist in estimating remaining strength of corroded pipe. ▪ Better modeling for growth of defects resulting from 3rd party damage. ▪ Additional corrosion assessment models targeted to corrosion at welds, interaction of closely spaced corrosion defects, etc. ▪ Interaction of material defect and damage with corrosion. ▪ Technical and economic justification of alternative pipe designs, including composite pipe (see below).	▪ "Self-healing" pipe.
	▪ **Higher grade/strength steels:** Installation of thicker or higher strength steels (>X70) may add to damage and defect resistance, and lower total costs, but may be offset by complications in joint welding, tensile strength, flexibility of pipe during installation, or resistance to crack propagation or corrosion when they appear.	▪ Seam weld integrity and fracture arrest properties up to X70 steel are well-proven, but still uncertain in higher strength steels. ▪ Girth weld assessment techniques are well-established for traditional materials and thicknesses, but need further development for newer materials.	▪ Decision-making , condition-analysis, and operating procedure protocols to optimize use of higher grade/strength steels. ▪ Improved assessment and inspection techniques for X80 steels; application of ultrasonics and development of improved "engineering critical assessment" techniques.	▪
	▪ **Higher design pressure:** Design pressures govern the maximum volume of gas or liquid throughput in a pipe. Pipes designed to allow higher pressure would allow greater volume of gas or liquid to be moved through a given diameter of pipe without adversely affecting safety or integrity.	▪ Current design pressures are generally less than 1435 psig, and most are 1000 psig and below.	▪ Use of design pressures up to 2800 psig and beyond with equivalent or enhanced pipeline integrity and safety.	▪

Areas of Focus	R&D Issues	Background	Near-Term R&D (0-3 years delivery)	"Next Generation" R&D
	▪ **Welding & joining techniques:** Welds and joints, particularly in replacement or repair situations, have different performance characteristics and failure factors than the pipe itself.	▪ Weld assessment techniques are well developed for traditional materials and thicknesses, but need further development for newer materials or X80 and above. ▪ Weldability of >X80 steels is not fully established. ▪ Products are available for strength levels up to X100, but use, installation and performance factors have not been fully established.	▪ Improve knowledge on weldability and weld metal requirements for X80-X100 steels. ▪ Improve process, burn through limits and inspection methods for welding on in-service pipe. ▪ Improved grading of weld defects for new or replacement pipe projects.	▪
	▪ **Composite pipe:** Pipes made of or layered with materials other than steel may exceed current performance standards or allow greater flexibility or lower cost in challenging installation conditions.	▪ Composite Reinforced Line Pipe (CRLP) thermoset/steel liner designed to allow leakage prior to rupture. Enables operation at ~3000 psi.	▪	▪ Thermoplastic resins. ▪ Installation/operating procedures and standards. ▪ Validation of long-term reliability.
	▪ **Pipe coatings:** Factory-applied coatings help prevent external corrosion and maintain pipe integrity in ground. Field-applied coatings at joints or repair sites have different costs and performance factors than factory-applied materials. Proper coatings are one of the most significant factors in ensuring pipe integrity.	▪ Factory-applied Fusion Bond Epoxy in North America, Triple Layer in Europe. ▪ High abrasion-resistant coatings for pipe inserted in horizontal directional drilling applications	▪ New test methodologies to predict long-term performance of coatings under variables of temperature, soil conditions, and installation and repair techniques. ▪ Development of decision methodologies for optimizing coating choices in given installation conditions. ▪ Improved compatibility and performance factors between factory- and field-applied coatings. ▪ Field-applied coatings with cost and performance factors of factory-applied coatings.	▪ Intelligent coatings that monitor their condition.
Enhanced Operations, Controls and Monitoring: Regardless of the quality of the materials, pipeline equipment will degrade over time and repairs will be necessary for successful safety and integrity maintenance. Improved technologies for operating	▪ **Pipe location (steel and plastic):** The specific location of pipe in the ground may be difficult to ascertain over time due to settling, ground shifts, surface activity and other factors. Quick, accurate location saves time and cost of maintenance and repair, as well as allowing accurate marking to protect against 3rd party damage. *(This item is also in the "Damage Prevention" section)*	▪ A variety of location techniques are available, with varying degrees of accuracy depending on pipe material, soil, depth and other on-site factors.	▪ Magnetic plastic pipe. ▪ Ground penetrating radar.	▪

Areas of Focus	R&D Issues	Background	Near-Term R&D (0-3 years delivery)	"Next Generation" R&D
technologies for operating, controlling and monitoring the safety and integrity of pipelines will ensure safety and lower operation and maintenance costs.	▪ **Stress Corrosion Cracking (SCC) detection & control:** SCC is a form of environmental cracking that results from the interaction of several factors including the chemistry of the soil around the pipe, the temperature of the commodity in the pipe, the chemistry of the steel pipe, and the mechanical stress on the pipe.	▪ While SCC is better understood today than when first discovered in the late 1950s– what causes it, how it grows and arrests, and the ability to predict the likelihood of its occurrence - it still presents challenges in prevention and management/control. ▪ Current in-line inspection tools ("pigs") have a very high false-positive detection rate, leading to needless and expensive confirmation digs.	▪ Characterization of two distinct classes of SCC having different occurrence and impact patterns. ▪ Improved coatings to impede environmental influences. ▪ Basic operating parameters to retard growth/influence arrest ▪ Ultrasonic "smart" pigs for crack detection in gas pipelines. ▪ Adaptation of current magnetic flux leakage (MFL) pigs to detect SCC. *(DOE)* ▪ Generally improving the sizing and grading capabilities of all crack detection pigs. ▪ Expanding available pigs through new technologies; e.g., electromagnetic acoustic transducers (EMATs). ▪ Improved understanding of the role and impacts of soil chemistry on the initiation, growth, and arrest of SCC. ▪ Combined acoustic/electro-magnetic sensors to locate and gauge SCC. *(DOE)*	▪ Understanding and assessing the impact on SCC of shifting pipeline operating load patterns and increased system flexibility.

Areas of Focus	R&D Issues	Background	Near-Term R&D (0-3 years delivery)	"Next Generation" R&D
	▪ **External corrosion control:** Buried pipe is surrounded by conditions highly conducive to the creation of corrosion on the pipe surface. Without monitoring and mitigation, corrosion can severely reduce the safety and service of buried pipe. Installation techniques and 3rd party damage monitoring are also significant factors. *(See "Damage Prevention and Leak Detection" section below).*	▪ Factory- and field-applied coatings play a significant role in corrosion protection. ▪ Monitoring and maintenance of cathodic protection (CP) systems help mitigate the spread of corrosion. ▪ CP is the critical backstop to coating failure, and is the first-line defense against corrosion for uncoated pipe. ▪ Direct assessment (DA) measures the stray electrical signals that result from a coating anomaly thereby identifying a potential corrosion site. ▪ Interference effects from other infrastructures (e.g., overhead power lines) on CP systems is increasing as utility right-of-ways (ROWs) become more congested	▪ Determining the performance of commercially-available coatings under various environmental and operating conditions. ▪ Developing protocols for the conduct and evaluation of field validations of Direct Assessment (DA). ▪ Understanding the seasonal variations in cathodic protection (CP) effectiveness. ▪ Developing models for predicting corrosion wall loss from CP system data. ▪ Developing new CP design tools using system-wide data that allow for greater customization for CP. ▪ Establishing the correlation between soil conditions and microbiologically-induced corrosion (MIC). ▪ Developing improved models for interpreting CP data.	▪ Developing above-ground tools – as an alternative to pigs - that can adequately interrogate buried pipe to determine its condition and locate defects.
	▪ **Internal corrosion control:** Internal corrosion can be caused by corrosive products or microbes carried in the pipeline. Internal surfaces can benefit from cathodic protection, but not from protective coatings. Internal corrosion should be suited to the application of a Direct Assessment (DA) technique that identifies locations where internal corrosion is likely to occur.	▪ Potentially harmful bacteria are always present in the gas stream, but require water to multiply. ▪ Preventing/managing internal corrosion involves pre-introduction and in-the-stream strategies that have to be understood in terms of their potential collateral impacts on the pipeline system.	▪ Determining the morphology of corrosion sites to identify the cause(s) of corrosion ("fingerprinting"). ▪ Developing environmentally-benign biocides to control microbiologically-induced corrosion (MIC). *(DOE)* ▪ Understanding the impact of hydrocarbon condensates in the gas stream as either a promoter or inhibitor of internal corrosion. ▪ Developing sacrificial probes that indicate MIC activity. ▪ Developing internal corrosion DA methodologies. ▪ Identifying and determining the impact of system operating conditions (e.g., "upsets") on the onset and growth of corrosion. ▪ Developing tests to identify MIC bacteria species.	▪

Areas of Focus	R&D Issues	Background	Near-Term R&D (0-3 years delivery)	"Next Generation" R&D
	▪ **Risk assessment & management:** Monitoring technologies produce a vast matrix of data about the condition and integrity of a pipeline. Comprehensive analysis of that data and prioritization and targeting of maintenance decisions are keys to cost-effective operation and maximum safety.	▪ Generally acceptable methods for risk and reliability analysis are known and available.	▪ Improve awareness of factors (welds, repair materials and techniques, mechanical properties, mechanical surface loadings, etc.) that influence the reliability of older pipelines.	▪
Damage Prevention and Leak Detection: Damage by 3rd party contact or intrusion or by environmental causes can cause unexpected harm to buried pipe, increasing the risk of gas losses or incidents. Improved non-destructive and non-intrusive monitoring technologies to detect 3rd party damage or environmental impacts when they occur will enable improved and more frequent monitoring to detect damage in its earliest stages. Third-party damage involves (1) damage that leads to instantaneous failure; and, (2) damage that grows to failure over time. Prevention is the only strategy for (1), while (2) requires detection, assessment, and repair or removal.	▪ **In-line inspection (ILI) for damage and defects:** A variety of "smart" pigs and other in-line inspection technologies can monitor for, detect and measure corrosion, cracks and other forms of damage to pipe walls.	▪ Available tools give detailed readings of existing corrosion damage or defects, but are less accurate for mechanical damage, and cannot detect mechanical damage in gas lines.. ▪ Advances are still needed on procedures for evaluating and aggregating data to accurately assess remaining strength of pipe and determining or prioritizing appropriate mitigation. ▪ Overall, there is a need for ILI standards regarding tool capabilities and inspection results, and standard validation protocols for ILI performance.	▪ Improved ILI for mechanical damage. ▪ Improved ILI corrosion grading. ▪ Improved techniques for assessing the interaction of clusters of corrosion pits. ▪ "Magnetic telescope" using electric current/superconducting magnet to identify corrosion areas. *DOE)* ▪ Sensing coils that wrap around pipe to map corroded surface areas. *(DOE)* ▪ Electromagnetic technology installed in "smart" pigs. *(DOE)*	▪ Definition of critical size and orientation (grading) of mechanical damage defects to allow proper maintenance response. ▪ Development of techniques to inspect "unpiggable" pipeline segments using ultrasound and guided waves.
	▪ **Pipe location (steel and plastic):** The specific location of pipe in the ground may be difficult to ascertain over time due to settling, ground shifts, surface activity and other factors. Quick, accurate location saves time and cost of maintenance and repair, as well as allowing accurate marking to protect against 3rd party damage. *(This item is also in the "Enhanced Operations, controls, and Monitoring" section)*	▪ A variety of location techniques are available, with varying degrees of accuracy depending on pipe material, soil, depth and other on-site factors.	▪ Magnetic plastic pipe. ▪ Ground penetrating radar. ▪ Flat plate or flexible mat to lay on ground to map subsurface objects. *DOE)*	▪

Areas of Focus	R&D Issues	Background	Near-Term R&D (0-3 years delivery)	"Next Generation" R&D
	▪ **Real-time sensors attached to the pipe:** Sensors in physical contact with the pipe can utilize acoustical or other readings to detect possible 3rd party contact, leaks or other signs of damage. Early detection of 3rd party contact may be significant in preventing delayed pipe failure from resulting cracks or corrosion.	▪ Acoustic signal propagation is more readily monitored in gas than liquid pipelines. ▪ Acoustic monitoring technologies are just beginning field testing.	▪ Improved technologies to pinpoint exact location of damage or intrusion. ▪ Adaptation of leak detection technologies in multiphase flow conditions. ▪ Extending the range of sensors to reduce the number of transmitters and receivers that have to be installed while assuring appropriate detection capability. ▪ Developing "acoustic libraries" to minimize false-positives and ensure that significant "hits" are identified. ▪ Developing means to detect "sideswipes" that only damage coating.	▪
	▪ **Real-time pipe line right-of-way (ROW) monitoring without pipe contact**	▪ Fiber optic lines buried above or along side a buried pipeline will detect small movement or vibration in the ground caused by the operation of large equipment near the pipeline.	▪ Determining the technical and economic feasibility of fiber optic lines to detect movement in proximity to the pipe. *(DOE)*	▪
	▪ **Satellite monitoring for encroachment and ground movement:** Satellite monitoring allows more consistent monitoring of factors that might alter High Consequence or Unusually Sensitive Area ratings. Changes in nearby land use may alter risk assessment protocols for pipeline operation. Ground movement patterns as a result of erosion, slope, water or other geologic/geophysical factors may affect pipeline integrity	▪ Right-of-way patrols are already a regulatory requirement, but satellite surveillance offers broader and more constant monitoring of surrounding conditions. Optical resolution levels and locational measurements are rapidly improving. Satellite monitoring can be highly accurate, cost-effective, and produce data that is readily integrated into other key data systems of the operator.	▪ Radar surveillance for ground movement and encroachment (e.g., negating cloud cover). ▪ Infrared detection of gas loss ▪ Optical technologies for right-of-way monitoring	▪

Areas of Focus	R&D Issues	Background	Near-Term R&D (0-3 years delivery)	"Next Generation" R&D
Arctic and Offshore Technologies: Arctic and offshore pipeline applications are subject to a variety of environmental, operational and maintenance conditions vastly different from traditional installations. Increased exploration in these areas will lead to increased demand for safe, cost-effective transportation materials and procedures.	▪ **Siting considerations:** Slope and sediment stabilities, pressures, temperatures, monitoring and repair access, saline environments and other factors provide unique siting considerations for off-shore installations. Seasonal temperature fluctuations and extremes, isolated distances and environmental protections affect Arctic applications.	▪	▪ 3-D analysis of motion and force impacts on buried pipe. *(MMS)* ▪ Modeling of submarine slope stability under critical loading conditions. *(MMS)*	▪
	▪ **Materials performance:** Unique temperature and pressure environments, as well as saline conditions for off-shore installations, may alter performance characteristics and evaluation protocols for conventional materials.	▪	▪ Assessment of performance and reliability of double-walled pipe for Arctic offshore applications compared to conventional pipe. *(MMS)* ▪ Specifications for cathodic protection in saline environments. *(MMS)*	▪
	▪ **Inspection/maintenance technologies and procedures:** Environmental conditions and isolated distances will make inspection and maintenance operations more difficult. Damage assessment protocols may vary from those proven in conventional installations.	▪	▪ Reliable in-line test procedures and instrumentation. *(MMS)* ▪ Technologies/ methodologies for inspecting and evaluating weld, corrosion and mechanical damage defects under extreme environmental conditions. *(MMS)*	▪ Alternative to hydrotesting to prove fitness for service in sensitive, remote environmental areas.
	▪ **Operational integrity:** Leaks or other failures in submarine or Arctic installations may have longer detection and response times than in more conventional installations, resulting in greater reliance on accurate, dependable systems and monitoring or inspection devices.	▪	▪ Accurate methods to model and predict liquid formation and impacts in submarine gas pipelines. *(MMS)*	▪