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NATURAL GAS PIPELINES

Greater Use of Instrumented Inspection Technology Can Improve Safety

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The Honorable Ernest F. Hollings
Chairman, Committee on Commerce,
Science, and Transportation
United States Senate

The Honorable Norman Y. Mineta
Chairman, Subcommittee on Surface
Transportation
Committee on Public Works and
Transportation
House of Representatives

The Honorable Philip R. Sharp
Chairman, Subcommittee on Energy
and Power
Committee on Energy and Commerce
House of Representatives

This report addresses inspection techniques available to determine and maintain the structural integrity and safety of natural gas pipelines and to improve the baseline knowledge of their condition. The report focuses on the use, capabilities, and limitations of instrumented internal inspection technology for inspecting natural gas transmission pipelines.

We are sending copies of this report to the Secretary of Transportation, the Acting Administrator of the Department of Transportation's Research and Special Programs Administration, and other interested parties. We will make copies available to others upon request.

This work was performed under the direction of Kenneth M. Mead, Director, Transportation Issues, who can be reached at (202) 275-1000 if you or your staff have any questions. Other major contributors are listed in appendix V.

J. Dexter Peach
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Executive Summary

Purpose

The Research and Special Programs Administration (RSPA) of the Department of Transportation (DOT) is responsible for the safety of about 267,000 miles of interstate natural gas transmission pipelines. Each year several hundred pipeline incidents (i.e., ruptures and leakages) occur, often resulting in deaths and damage to property or the environment. Since most natural gas pipelines were constructed in the 1950s and 1960s, the risk of damaging incidents in these aging pipelines will only increase.

To improve the safety of natural gas and hazardous liquid transmission pipelines, the Congress passed the Pipeline Safety Reauthorization Act of 1988 (P.L. 100-561, approved Oct. 31, 1988) directing DOT to (1) prepare a feasibility study on requiring the use of an instrumented internal inspection device called a "smart pig" to inspect transmission pipelines and (2) establish regulations requiring that new or replacement pipeline facilities, to the extent practicable, be capable of accommodating smart pigs. As of mid-September 1992, the Congress was also considering new legislation that would require pipelines to be inspected with smart pigs under certain circumstances. This report focuses on the use, capabilities, and limitations of smart pig inspections; federal regulations and guidelines for smart pig inspections; and the status of RSPA's efforts to comply with P.L. 100-561.

Background

Maintaining the structural integrity and safety of natural gas pipelines requires the use of several technologies—external corrosion controls, visual inspection after excavations, hydrostatic pressure testing, and smart pig inspection. Hydrostatic testing—forcing water through a pipeline at high pressure—provides data on the pipeline's operating pressure integrity and identifies significant pipeline defects by exposing the pipeline to pressure above its maximum operating pressure. Smart pig inspection produces data on the metal integrity and condition of the pipeline. Neither technique can be substituted for the other because each produces information unique within its own scope.

Magnetic-flux leakage is the principal technology used in smart pig inspection of natural gas pipelines. This technology, which identifies defects by measuring changes in the pipe wall's magnetic field, can locate external and internal corrosion and other pipe flaws and can monitor pipeline condition. Pipe segments where flaws are identified can then be excavated and repaired or replaced before leakage or rupture occurs.

Results in Brief

The use of smart pigs is the only pipeline inspection technique that can detect internal and external corrosion without excavating the pipe. Pipeline corrosion is the second leading cause of pipeline incidents after accidental excavation damage. Smart pigs can also detect other pipe flaws, such as gouges and dents, that weaken the pipe's structural integrity. Smart pigs, however, cannot detect defects such as longitudinal cracks and metal loss in pipe welds. Furthermore, while many pipelines can accommodate smart pigs, others cannot due to operational limitations. In those cases in which smart pigs can be used, this technology can reduce pipeline incidents.

There are no federal regulations on smart pig use or the frequency of smart pig inspections. As of September 1992, RSPA had not completed the feasibility study on smart pigs that P.L. 100-561 mandated be issued by May 1990 and had not issued the mandated regulations requiring new or replacement pipelines to accommodate smart pigs. RSPA officials said the delays were the result of resource shortages and the need to give greater attention to other higher priority mandates. Due to the effects of corrosion over time, pipelines tend to have more ruptures and leakages as they age. These incidents can result in fatalities, injuries, and property damage. Considering smart pigs' potential to improve pipeline safety, RSPA needs to complete the mandated feasibility study and regulations.

Principal Findings

Smart Pigs Can Improve Pipeline Integrity and Safety

From 1985 through 1991, 1,726 natural gas pipeline incidents involving 131 fatalities and 634 injuries occurred in the United States. The leading cause by far of pipeline failure is accidental damage caused by excavation by third parties and the second leading cause is corrosion. Smart pig inspections have demonstrated that they can identify internal and external corrosion and certain other pipeline flaws before leakage or rupture occurs. Hydrostatic testing identifies significant defects by causing the pipe segment to fail during testing but provides no information about the extent or severity of remaining corrosion damage.

Of the 15 U.S. and 3 Canadian natural gas pipeline companies responding to a GAO questionnaire, 9 U.S. and the 3 Canadian companies reported that they had success in using smart pig technology. Smart pig inspections provided these companies with data on the location and size of corrosion damage in their pipelines. Some companies used first-generation smart pigs because of their availability and said the pigs could detect corrosion at lower cost than second-generation smart pigs. A few companies had used second-generation smart pigs, which have advanced capabilities to provide data on pipe flaws. The nine U.S. companies reported that about 27,000 miles, or about 29 percent, of their interstate pipelines could accommodate smart pigs.

Smart pig inspections can improve pipeline integrity and safety. For example, in one case a smart pig inspection detected the presence of corrosion in a gas pipeline company's transmission line. This line later ruptured, causing five deaths and property damage. According to the state gas pipeline safety office, the incident could have been prevented if the company had used the data available from the smart pig inspection to take timely corrective action. Another company found smart pigging so successful that its current 20-year plan includes pig inspection of all its lines. A third pipeline company voluntarily invested $100 million to make 9,000 miles of its pipelines "piggable" and has reported many advantages in smart pigging.

Smart pig technology has some operational limitations, such as not being able to (1) detect longitudinal cracks and metal loss in a pipe's circumferential welds and (2) locate potential seam failure in electric-resistance-welded pipes (a welding process used before the 1970s). Also, smart pigs cannot be used in pipes with sharp bends. Despite such limitations, smart pig inspection, supplemented by visual inspection through localized excavations, is currently viewed as the only reliable technique (short of somewhat random excavation, coupled with inspection by a hand-held ultrasonic instrument to detect internal corrosion) for detecting internal and external pipe corrosion. The companies reported costs of pigging ranging from about $650 to $2,400 per mile of pipeline.

Congressional Mandates Have Not Been Completed

There are federal pipeline safety regulations for external corrosion controls and hydrostatic testing, but none for smart pig use. Nevertheless, RSPA has recognized the capabilities of smart pig inspection and required some companies to use smart pigs to verify the integrity of their lines after a pipeline incident. Officials of several pipeline companies and state pipeline inspection offices told GAO that federal regulations on the use of smart pigs would improve the knowledge of the condition and integrity of pipelines. In this regard, British Gas established smart pig inspection standards in 1983, and the Canadian government plans to adopt similar standards by July 1993.

The National Transportation Safety Board (NTSB) has recommended and the Congress has addressed requirements for the use of smart pigs. In 1987 NTSB recommended that RSPA require liquid petroleum and natural gas transmission operators to make modified and repaired pipelines piggable. Subsequently, P.L. 100-561 required DOT to establish minimum safety standards so that any newly constructed or replacement lines would be able to accommodate smart pigs. Almost 4 years after the legislation was passed, RSPA has not issued the regulations. Also, RSPA has not issued the mandated feasibility study, due by May 1990, on requiring the inspection of transmission lines with smart pigs. RSPA officials cited resource shortages and the need to give greater attention to other responsibilities as the primary reasons for the delays. As of September 1992, RSPA's study and a notice of proposed rulemaking for the required regulations were undergoing review and coordination within DOT.

Recommendations

GAO recommends that the Secretary of Transportation act to expeditiously (1) provide the Congress with the final report from the smart pig feasibility study mandated by P.L. 100-561, or notify the Congress when it will be available, and (2) issue the regulations mandated by P.L. 100-561.

In carrying out the above actions, DOT and RSPA should determine how smart pig technology can effectively be used in natural gas transmission pipelines, especially those in densely populated areas. They should consider the capabilities, limitations, and costs of smart pigs and the role that smart pig inspections should play in DOT's overall strategy for ensuring pipeline integrity and safety.

Agency Comments

GAO discussed the information contained in this report with officials in RSPA's Office of Pipeline Safety. Agency officials generally agreed with the facts presented, and their comments were incorporated where appropriate. However, as discussed with the addressees' offices, in order to expedite the issuance of this report, GAO did not obtain written agency comments on a draft of this report.

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Abbreviations

CSA	Canadian Standards Association
DOT	Department of Transportation
EPA	Environmental Protection Agency
GAO	General Accounting Office
INGAA	Interstate Natural Gas Association of America
NACE	National Association of Corrosion Engineers
NTSB	National Transportation Safety Board
OMB	Office of Management and Budget
OPS	Office of Pipeline Safety
PCB	polychlorinated biphenyl
RSPA	Research and Special Programs Administration
TRB	Transportation Research Board

Introduction

The Department of Transportation (DOT) is responsible for developing, issuing, and enforcing safety regulations for more than 1.6 million miles[1] of natural gas pipelines in the United States. The safety of these pipelines is becoming an increasing concern as they age. Most of the nation's natural gas pipelines were constructed in the 1950s and 1960s; 10 percent of the lines were constructed before 1950 and 9 percent before 1940. Because of the toxicological and flammable characteristics of natural gas, its leakage from pipelines can cause severe damage to human health, property, and to a lesser extent, fish and wildlife and the environment.

Natural Gas Transportation and Inspection of Pipelines

Natural gas is transported through pipelines under high pressure. Pipelines are generally constructed of steel and coated with a protective material. They are made in various diameters, ranging from 4 inches to 48 inches, and with various wall thicknesses. Pipe sections consisting of two 20-feet-long sections are welded together for transportation to the construction site for weld connections in the field. At various intervals, pumping stations are provided to boost line pressure.

The primary component of natural gas is methane, which is flammable when mixed with air. Natural gas may leak in small quantities from cracks, flaws, or damaged areas of the pipeline. Because natural gas is considerably lighter than air, it rises and tends to disperse rapidly. Dangerous conditions occur when significant gas quantities are released into the atmosphere from a leaking pipe. The gas will burn if ignited and can explode if ignited in a confined space.

A natural gas pipeline must be designed and constructed to withstand the operational stresses associated with transporting natural gas, because it is transported under pressure. The pipe must also be protected during its operational life from damage and degradation from other causes such as corrosion, mechanical damage, fatigue, and stress-corrosion cracking.[2] To determine and maintain the structural integrity and safety of natural gas pipelines and to improve the baseline knowledge of their condition, a combination of external corrosion controls and inspection techniques is used.

[1]This figure includes 267,000 miles of interstate natural gas transmission lines. The remainder includes gathering and distribution lines. This report focuses on the 267,000 miles of transmission lines.

[2]Such cracking is characterized by multiple longitudinally oriented tight cracks—usually accompanied by poor or distorted coating in a coated pipeline.

Pipelines are inspected by various methods, including (1) visual inspection techniques, such as line walking (walking along the pipeline), line walking with a hydrogen flame ionization detector,[3] and the use of light aircraft or helicopters to check for evidence of leaking, such as dying vegetation, cavities in the ground, or water bubbles; (2) X-raying pipe welds; (3) hydrostatic pressure testing of the pipeline—forcing water through a segment of pipeline to cause pipeline defects, if any, to rupture; and (4) placing an instrumented device, called a smart pig, inside the pipes to record flaws as the pig is transported through the pipes by natural gas. Hydrostatic testing provides information on the pressure integrity of the pipeline, while smart pigging produces information on the metal integrity and condition of the pipeline. Neither technique can be substituted for the other because each produces information unique within its own scope. The uses and limitations of the various protection and inspection techniques are discussed in detail in appendix I. Instrumented inspection is discussed below.

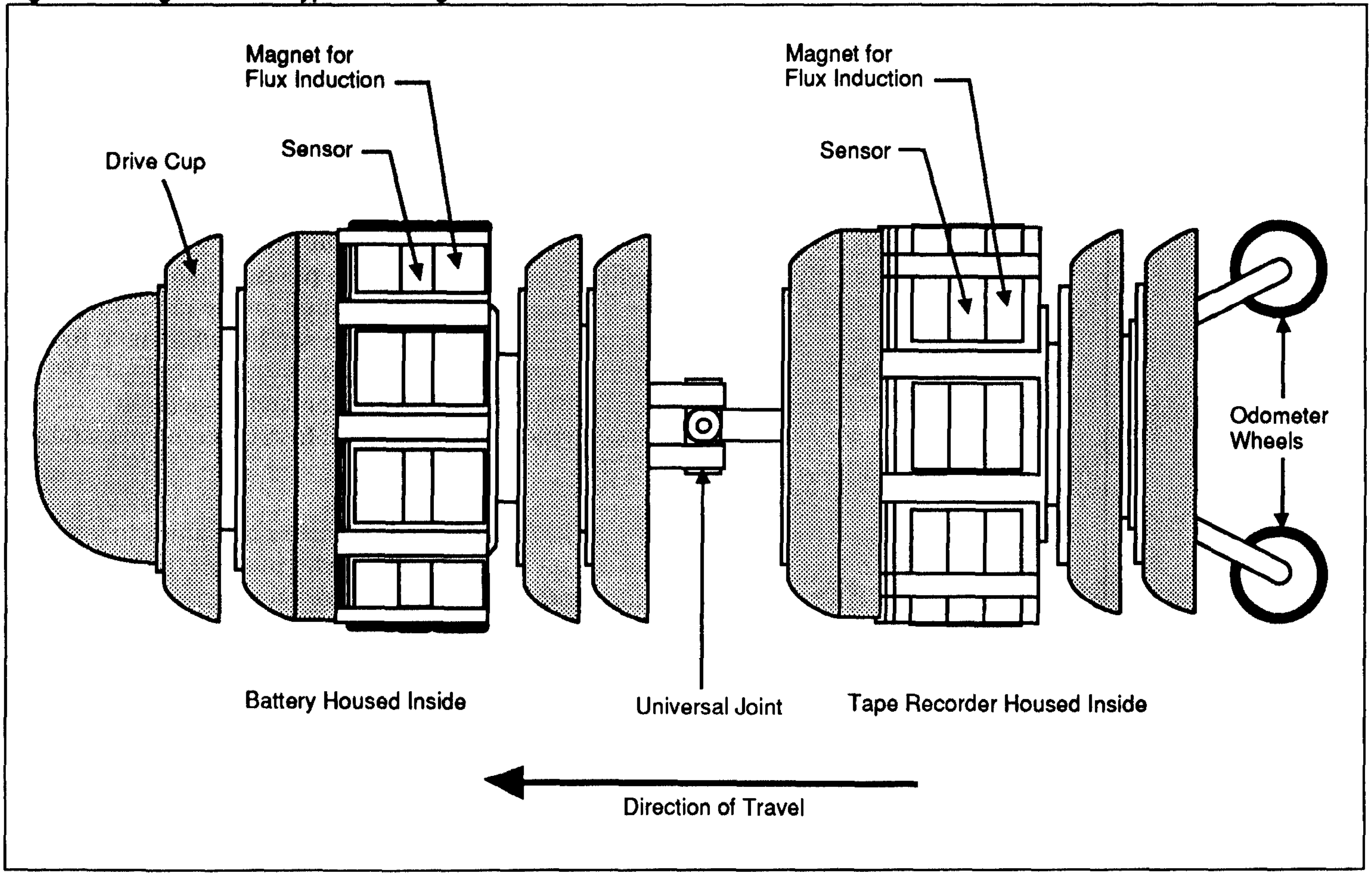
Since the 1960s smart pigs have been used by some companies to inspect pipelines.[4] Pigs are usually owned by vendors who manage the inspection and interpret the results for the pipeline operator on a contract basis. The pig is launched inside a "piggable" pipeline through a launch trap, propelled by a transporting medium, and received through a receiver trap.

Smart pigs carry ultrasonic or magnetic-flux leakage measuring instruments to monitor pipeline condition and to identify external and internal corrosion and other flaws and features. Smart pigs carry their own battery, tape recorder, electronics, and odometer. (See fig. 1.1.) The pigs can be a single unit or consist of multiple units linked together so that pipe bends can be negotiated. In addition to the ultrasonic and magnetic-flux smart pigs, there are other types of smart pigs. For example, the deformation pig, or caliper pig, can determine the deformation and slope of the pipeline and measure changes in the pipeline's position. Smart pigs also have operational limitations that preclude their use for inspecting some pipelines and detecting certain flaws. The uses and limitations of smart pigs are discussed in detail in chapter 2. Appendix II provides details on smart pig technologies, commercialization, and available sizes.

[3]The instrument samples the air over the pipeline. A low-level alarm from the instrument means that there is a gas leak in the pipeline.

[4]Cleaning pigs have been used in pipelines since 1890 to remove rust, paraffin (wax), scale, and other deposits. These pigs are generally used before smart pig inspections to clean the line to enable the smart pig to perform better.

Figure 1.1: Magnetic-Flux Type Smart Pig



Source: Vetco Pipeline Services.

Federal Pipeline Safety Responsibilities

The Natural Gas Pipeline Safety Act of 1968, as amended (49 U.S.C. app. 1671 et seq.), and the Hazardous Liquid Pipeline Safety Act of 1979, as amended (49 U.S.C. app. 2001 et seq.), authorize DOT to establish and enforce safety standards for pipelines used to transport natural gas and hazardous liquids. DOT has delegated its pipeline safety responsibility to its Research and Special Program Administration (RSPA). RSPA's Office of Pipeline Safety (OPS) and its five regional offices implement the national program of pipeline regulation, enforcement, training, and research.

RSPA administers a pipeline safety inspection and enforcement program for the transportation of natural gas and hazardous liquids. RSPA inspectors review pipeline records and facilities, perform accident investigations, and make follow-up and/or construction inspections. Construction inspections allow inspectors an opportunity to view a pipeline before it is buried. Follow-up inspections are made to determine if previously identified problems have been corrected. Federal safety regulations on external pipe coatings, cathodic protection, and hydrostatic pressure testing were established in November 1970.

Recent legislation and bills being considered by the Congress specifically address the use of smart pigs. The Pipeline Safety Reauthorization Act of 1988 (P.L. 100-561, approved Oct. 31, 1988) required the Secretary of Transportation to report to the Congress on the feasibility of requiring the inspection of transmission pipelines with smart pigs and to establish, by regulation, minimum federal safety standards requiring that new or replacement pipelines, to the extent practicable, be capable of accommodating smart pigs. As of mid-September 1992, final congressional action was pending on legislation that would require, under certain circumstances, the inspection by smart pigs of natural gas transmission pipelines in densely populated areas and hazardous liquid pipelines in environmentally sensitive or densely populated areas.

The National Transportation Safety Board (NTSB), an independent federal agency, is also involved in federal pipeline safety activities. It is responsible for investigating, determining probable cause, making safety recommendations on, and reporting the facts and circumstances of all pipeline accidents which result in a fatality or substantial property damage. NTSB also, among other things, evaluates the adequacy of safeguards and procedures concerning the transportation of natural gas and hazardous liquids.

Objectives, Scope, and Methodology

We performed this work to develop data on the use of smart pigs and to assist the Congress in its oversight of natural gas transmission pipeline safety. This information should also assist RSPA in its rulemakings on pigging. Specifically, our work focused on (1) the use, capabilities, and operational limitations of smart pigs and (2) federal regulations and guidelines for smart pig inspections and the status of RSPA's efforts to comply with Public Law 100-561 requirements.

To address these objectives, we reviewed the engineering literature of smart pig manufacturers in the United States, Japan, Great Britain, and Germany; discussed with pig manufacturers current pig technology and advances expected in such technology; attended a conference on smart pig technology; attended Technical Hazardous Liquid and Gas Pipelines Safety Standards Committee meetings sponsored by RSPA; physically examined selected smart pigs; observed an ultrasonic pig in operation; reviewed engineering literature on smart pig inspection; observed hydrostatic pressure testing; and reviewed NTSB documents on pipeline incidents.

To obtain further information on smart pig technologies used in the natural gas industry, we mailed a questionnaire to a judgmentally selected group of 23 natural gas transmission companies, including 20 U.S. and 3 Canadian companies. We received completed questionnaires from 18 companies, including the 3 Canadian companies. Not all companies responded to all the questions. The five U.S. companies that did not respond did not provide any reasons for not responding to our questionnaire. The 15 U.S. companies that responded had 102,440 miles of interstate transmission pipelines, or 38.4 percent of the 267,000 total miles of natural gas interstate transmission pipelines in the United States. About 33,443 miles of their pipelines, or 32.6 percent, are piggable. Of the 15 U.S. companies, 9 indicated that they had used smart pigs. About 26,795 miles, or 29 percent, of their total 92,146 miles are piggable. The three Canadian companies had 21,158 miles of pipelines, of which 20,463, or 97 percent, are piggable. All three Canadian companies indicated they had used smart pigs.

Of the 23 companies selected to receive the questionnaire, 15 were members of the Interstate Natural Gas Association of America (INGAA). To supplement the information, we included other natural gas pipeline companies that are not members of INGAA. Appendix III lists the natural gas pipeline companies that completed the questionnaire. To augment questionnaire results, we interviewed interstate natural gas pipeline operators that are modifying their lines for smart pig inspection. We also interviewed officials of selected companies, some that reported using smart pigs and some that did not use smart pigs. In addition, we interviewed officials of smart pig manufacturers, including Tuboscope, Vetco, and T.D. Williamson (United States); Pipetronix (Germany); Rosen (Germany); and British Gas.

To obtain information on pipeline safety and integrity and the use of smart pigs in the United States, we interviewed representatives of the National

Transportation Safety Board and RSPA's Office of Pipeline Safety, including two regional offices. We also interviewed pipeline inspection office officials from certain randomly selected states—Alabama, Alaska, Arizona, California, Florida, Georgia, Illinois, Kentucky, Ohio, and West Virginia—to obtain their views on the use of smart pigs and the need for federal regulations on smart pig inspections. We also interviewed officials of Canada's National Energy Board in Calgary, Alberta, to obtain information on the use of smart pigs in Canada and on Canadian standards and regulations for smart pigs.

We conducted our review between March 1991 and September 1992 in accordance with generally accepted government auditing standards. We discussed the information in this report with officials in RSPA's Office of Pipeline Safety. These officials generally agreed with the facts presented, and we incorporated their comments where appropriate. However, in order to expedite issuance of this report we did not obtain written agency comments on a draft of this report.

Operational Capabilities, Limitations, and Costs of Smart Pig Inspection

From 1985 through 1991, 1,726 natural gas pipeline incidents (i.e., ruptures and leakages) involving 131 fatalities and 634 injuries occurred in the United States. The second leading cause of a pipeline incident is internal and external corrosion. Smart pig inspections have demonstrated the potential for identifying internal and external corrosion and other pipeline flaws and reducing pipeline incidents. Smart pig use, supplemented by visual inspection through localized excavations, is the only reliable technique currently available (short of somewhat random excavation, coupled with inspection by a hand-held ultrasonic instrument to detect internal corrosion) for detecting internal and external pipe corrosion.[1] Smart pigs, however, have some operational limitations, since some pipelines cannot accommodate smart pigs and smart pigs cannot determine certain pipeline flaws.

Two types of magnetic-flux[2] smart pig technology are available—first-generation and second-generation. First-generation magnetic-flux technology is about 25 years old. State-of-the-art second-generation technology, which is only about 5 years old, has more advanced capabilities for detecting pipeline flaws.

Trends in Pipeline Performance

In 1985, 331 natural gas pipeline incidents resulting in 26 fatalities and 106 injuries were reported to RSPA. In 1991—the latest year for which data were available—233 incidents resulting in 14 fatalities and 89 injuries were reported to RSPA. According to RSPA, the number of written incident reports submitted by natural gas operators sharply declined beginning in 1985 as a result of the revised federal reporting requirements, which increased the reporting threshold for property damage.

Natural gas pipeline incidents and casualties in transmission, distribution, and gathering lines from 1985 through 1991 are shown in table 2.1.

[1]W.K. Holm, "Use of Magnetic Inspection Pigging Provides Valuable Tool in Pipeline Maintenance," Oil and Gas Journal, Vol. 82, No. 35, Aug. 27, 1984. The author also states that random visual inspection of a pipeline can give the erroneous impression that the line is in much better or much worse condition that it actually is. The author further states that the 100-percent coverage provided by an internal pig inspection accurately gives the corrosion picture.

[2]Generally, only magnetic-flux smart pigs are used to inspect natural gas pipelines. Because ultrasonic smart pigs require a liquid medium in which to operate (see app. II), using them in natural gas pipelines requires emptying the pipelines of natural gas and refilling them with a liquid medium.

Table 2.1: Natural Gas Pipeline Incidents and Casualties, 1985-91

		Casualties	
Year	**Incidents**	**Fatalities**	**Injuries**
1985	331	26	106
1986	219	23	106
1987	229	9	101
1988	258	18	87
1989	257	36	78
1990	199	5	67
1991	233	14	89
Total	**1,726**	**131**	**634**

Source: Data for 1985-89 are from Annual Report on Pipeline Safety, Calendar Year 1989, Office of Pipeline Safety, Research and Special Programs Administration. Data for 1990-91 were provided by the Office of Pipeline Safety.

Causes of Pipeline Failures

RSPA requires pipeline operators to report a pipeline failure and to specify the reasons for the failure, such as outside-force damage, corrosion, and defective materials. According to RSPA records, the leading cause by far of pipeline failure is outside-force damage—accidental damage caused by third-party excavation. While accounting for fewer incidents, the second leading cause is internal and external corrosion. Internal corrosion occurs when water, hydrogen sulfide, or carbon dioxide is present in the gas or liquid transported through the pipeline. External corrosion occurs on pipe that is exposed to moisture.

Older pipelines tend to have more leakage or ruptures than do newer lines because the effects of corrosion over time reduces the older pipe's ability to support stress. Table 2.2 shows the causes of and amount of property damage and fatalities and injuries resulting from the 233 natural gas pipeline incidents in 1991 (the latest year for which data were available) in transmission, gathering lines in populated areas, and distribution lines.

Table 2.2: Causes of Natural Gas Pipeline Incidents in 1991

Cause	Incidents	Property damage	Casualties: Fatalities	Casualties: Injuries
Damage from outside forces	139	$ 8.456[a]	8	44
External corrosion	12	0.814	1	5
Internal corrosion	11	1.305	0	1
Construction/material defect	11	0.286	1	4
Accidently caused by operator	4	0	0	2
Other[b]	56	8.658	4	33
Total	**233**	**$19.519**	**14**	**89**

[a]Dollars in millions.

[b]Landslides, ground movement, and freeze damage.

Source: Data provided by the Office of Pipeline Safety.

Smart Pigs Can Find Potential Defects Before Ruptures Occur

Smart pig technology is the only pipeline inspection technique available to detect internal and external corrosion without excavating the pipeline. Corroded areas and other pipeline flaws identified by smart pigs can be repaired or replaced before they rupture. Smart pigging also produces data on the metal integrity and condition of the pipeline. Without such data, it is not possible to evaluate the total integrity and safety of the pipeline. In addition, smart pigging provides data for determining that nothing is occurring within the pipeline wall that will lessen the pressure integrity established by a hydrostatic test. Smart pigging does not require emptying the pipeline of the natural gas transported as hydrostatic testing does. According to one vendor, smart pigs can inspect a pipeline at an optimal rate of 53 miles to 72 miles of pipeline per day.

Smart Pig Inspection Identified Corrosion

According to a 1987 NTSB report,[3] on February 21, 1986, a section of an interstate gas company's 30-inch gas transmission line in Kentucky ruptured because of corrosion. The force of escaping gas tore 480 feet of the pipeline out of the ground and excavated an area 500 feet long, 30 feet wide, and 6 feet deep. The escaping natural gas ignited almost immediately and incinerated an area extending more than 900 feet north and south and 1,000 feet east and west. Five persons died and three other persons

[3]Texas Eastern Gas Pipeline Company Ruptures and Fires at Beaumont, Kentucky on April 27, 1985 and Lancaster, Kentucky on February 21, 1986, National Transportation Safety Board, Pipeline Accident Report PB87-916501, Feb. 18, 1987.

suffered injuries. Two houses were destroyed by fire; a house trailer, five buildings, and six automobiles were damaged or destroyed; and about 15 acres of pasture and woodland were burned.

NTSB, which investigated the rupture, stated that 5 months earlier a smart pig had detected the presence of generalized corrosion in the line. Previous close interval potential surveys to check the effectiveness of cathodic protection[4] had shown that close interval survey readings were functioning within the acceptable range. According to NTSB, the line operator failed to recognize that the pipeline was subject to a "shielding effect"—in this case, the line was laid over rock strata—which effects the reliability of such readings. According to the Chief Engineer of the Kentucky Public Service Commission's Gas Pipeline Safety Office, who also investigated the rupture, the rupture would have been preventable if the gas company had evaluated the level of corrosion data provided by the smart pig inspection company and taken timely corrective action.[5]

Successful Smart Pig Inspection Programs

According to an official of Tennessee Gas Pipeline Company (Tenneco), smart pigging of its lines has proven to be so successful that Tenneco's current 20-year plan includes pig inspection of all the company's transmission lines. Tenneco has 17,000 miles of pipeline, of which 60 percent is over 30 years old. Tenneco has averaged 500 miles of pigging each year, integrating information provided by the smart pig inspection into other pipeline information. Thus, pipeline segments are replaced and coated only when required.[6]

An official of American Natural Resources, a natural gas transmission pipeline company, told us that under its 10-year program, the company invested about $100 million to make 9,000 miles of its pipelines piggable. The remaining 3,000 miles in its network will be piggable by 1994. The official added that he found many advantages in smart pigging the company's pipelines, such as quicker location of corrosion and other flaws, improved knowledge of the condition of the pipelines, and less chance of incidents and the resulting liability.

[4]A method for controlling external corrosion by passing an electric current through a pipeline (see app. I).

[5]Texas Eastern Gas Pipeline Company's Line Rupture in Garrard County, Kentucky, on Friday, February 21, 1986, Preliminary Report, Kentucky Public Service Commission, p. 6. Field readings of the failed pipe showed a remaining wall thickness of 0.137 inch. The original wall thickness was 0.375 inch.

[6]Michael J. Davis, "Efforts for Verifying Pipeline Integrity," The National Association of Corrosion Engineers Annual Conference, Cincinnati, Ohio, paper 360, March 11-15, 1991, pp. 360/3 to 360/5.

Frequency of Smart Pig Inspections

Twelve of the 18 companies responding to our questionnaire stated that they had used smart pigs. Ten of the 12 companies responded to our question on how often they inspected their lines with smart pigs. Table 2.3 shows the wide range of inspection intervals they reported.

Table 2.3: Frequency of Smart Pig Inspection of Natural Gas Pipelines

Frequency of pig inspection	Number of companies
Only one time	3
On an as-required basis	3
Repeat inspection of certain pipeline segment	1
Based on risk assessment of the pipeline	1
Once every year	1
Once every 5 to 10 years	1
Total	**10**

Pipeline Flaws Identified by Smart Pigs

The 12 companies that have used pigs responded to our request to list flaws identified by magnetic-flux smart pigs. They reported that the pigs identified corrosion pitting, mechanical damage, axial and circumferential gouges, dents, manufacturing defects, and the location of girth welds, valves, and bends in pipelines. However, the pigs did not identify metal loss in circumferential welds and longitudinal cracks, or the integrity of external coatings, including the location of disbonded coatings. Table IV.2 in app. IV shows the number of companies reporting pipeline flaws identified by magnetic-flux smart pigs.

Companies' Comments on Using Smart Pigs

Companies we surveyed that had used smart pigs reported that pigs had the ability to determine the source and location of internal/external pipe problems, quickly locate anomalies, and establish existing pipeline conditions. Some companies also noted that smart pigs enabled them to rank repair work on the basis of the location and severity of problems identified, minimize pipeline downtime, plan effective maintenance, minimize costly loss of natural gas, ensure the pipeline is being operated and maintained in a safe manner, and evaluate the value of pipelines before sale or purchase of pipeline systems. Some companies also reported that smart pigs required substantial time to mobilize/demobilize. Table IV.3 in app. IV shows the number of companies that expressed comments on using magnetic-flux smart pigs.

Some companies cited examples in which smart pigging helped determine if there were any safety-related conditions in the pipeline. For example, a

Canadian company reported that the results of a high-resolution smart pig inspection enabled the company to perform a critical engineering assessment of corrosion damage. This assessment provided reliable estimates of the amount of pressure that would cause the pipe with reported corrosion damage to fail, thus allowing the company to repair the damaged pipe that might fail at the required hydrostatic test pressure.

As discussed in appendix I, hydrostatic testing identifies significant pipeline defects by causing them to fail during testing at pressures of 125 percent, or more, of the pipeline's maximum operating pressure. Hydrostatic testing provides only interim confidence in pipeline safety and no information about the extent or severity of the remaining corrosion damage. Furthermore, hydrostatic testing removes the pipeline from service until testing and needed repairs are completed.

Some companies also reported operational conditions that must be considered when using smart pigs. For example, one company said that the entire pipeline geometry must be known before using a smart pig. Another pointed out that pipelines had to be cleaned by a cleaning pig at an additional cost before a smart pig could be run. Two companies noted that the flow of gas has to be slowed for smart pig inspections, which results in revenue loss.

Some companies said that the use of smart pigs was unnecessary or unsuited to their pipelines. One company reported that its multidirectional-flow operating system makes it difficult to install permanent pigging facilities on some pipeline segments. A company with a 30-year-old pipeline system stressed its careful maintenance and monitoring of its lines and the fact that it has never had serious problems. The company said that considering the high cost and the reduction of natural gas flow through the pipeline associated with the use of smart pigs, plus the need to modify its lines for pigging at a cost of several million dollars, pigging would not be economically justified. Another company commented that smart pigs provide helpful information for determining the condition of pipelines on some occasions. However, on the basis of the company's experience, pigs do not provide reliable enough information for a "stand alone" determination of whether a pipeline may or may not be safe to operate.

Operational Limitations of Smart Pigs

First-generation, or low-resolution, smart pigs can locate corrosion. Additionally, a high-resolution smart pig provides reasonably accurate information on the length and depth of the flaw.[7] However, smart pigs have operational limitations such as the following that preclude their use for inspecting some pipelines:

- Smart pigs cannot negotiate a pipe with sharp bends, which many older natural gas pipelines have.
- Some pipelines have valves that do not fully open and can obstruct pig passage.
- Some smart pigs are not suitable for inspecting pipelines with thin pipe walls.
- An extreme range of temperature of the natural gas transported affects the operational capability of the pig.
- The velocity of the natural gas transported has to be reduced for proper operation of the pig. Reduction in the velocity of the gas results in the reduction of the rate of gas flow.
- Some pigs are not available in sizes to match pipe sizes.

In addition, we found that neither the magnetic-flux nor the ultrasonic pig technology has yet been developed to detect longitudinal cracks, locate potential pipe seam failure of electric-resistance-welded pipes (a welding process used before the 1970s), and detect metal loss in circumferential welds.[8] Representatives of three smart pig manufacturers told us that, over time, market demand should bring about further technology improvements that could overcome many of these limitations.

Assessment of Smart Pigs' Ability to Establish Pipeline Integrity

Ten of the 12 companies that had used smart pigs assessed the pigs' overall ability to establish pipeline integrity as average to exceptional. The remaining two companies did not provide an assessment of smart pigs' capability. Table 2.4 shows this range.

[7]John F. Kiefner and Patrick H. Vieth, "When Does a Pipeline Need Revalidation?," International Pipeline Rehabilitation Seminar, Houston, Texas, Jan. 29-31, 1992.

[8]Hydrostatic testing is of limited value in finding girth weld defects because the axial stress created by pressure is only one-third to one-half the circumferential stress. See J.F. Kiefner, R.W. Hyatt, and R.J. Eiber, NDT [Non-Destructive Testing] Needs for Pipeline Integrity Assurance, Final Report PR-3-624 to American Gas Association, Battelle (Columbus, Ohio: Oct. 6, 1986), p. 12.

Table 2.4: Assessment of Smart Pigs' Ability to Establish Pipeline Integrity

Type of pig	Assessments				
	Exceptional	Above average	Average	Below average	Poor
Magnetic-flux	1	3	6	0	0

See app. IV for details on the opinions of manufacturers and companies on classifications of smart pig technologies, reasons for using various types of smart pigs, and observations on specific capabilities of smart pigs.

Cost of Using Smart Pigs

Companies responding to our questionnaire stated that the cost of pigging depends on a number of variables, such as the type of pig used, diameter of the pipeline, cleanliness of the pipeline, length of pipeline pigged, level of competition among pig vendors, amount of corrosion reported (because the inspection data analysis and interpretation are paid on an hourly basis), and amount of excavation required to visually inspect areas where a pig has indicated anomalies.

These variables help to explain the broad range of costs reported by the nine companies that responded to our request for cost information. Overall, five companies reported that the costs of using first-generation pigs were lower than those of using second-generation technology. Three companies reported that the costs of using first-generation pigs were higher than those of using second-generation technology. One company reported that the costs of using first- and second-generation pigs were the same. Table 2.5 shows, over a 3-year period, the range of costs reported by the companies for using pigs per mile of on-stream pipeline. No company reported using smart pigs for inspecting out-of-service pipelines.

Table 2.5: Pigging Cost per Mile of On-Stream Pipeline

Year	Range	
	Low	High
1989	$650	$1,511
1990	650	1,700
1991	650	2,400

The only company that provided detailed cost information on pigging had used the second-generation British Gas pig and reported that the inspection cost of a first-generation pig is typically one-half to one-third of the inspection cost for a high-resolution or second-generation pig. However, this initial cost advantage is eliminated once the number of excavations required to investigate the anomalies indicated exceeds about 20. When the number of indications of severe corrosion is high, the total cost of restoring the integrity of a pipeline inspected by a first-generation pig will involve an additional cost of hydrostatic pressure testing.

In 1989 a Canadian gas pipeline company used a 34-inch, low-resolution magnetic-flux pig to inspect a 176-mile section.[9] The results showed extensive corrosion and the resulting need for 1,809 excavations to validate the pig inspection. Instead, the company decided to inspect the line with the British Gas high-resolution pig. This inspection showed that only three excavations would be required. The company saved money by reinspecting the line with the high-resolution pig rather than making the 1,809 excavations. We did not address the cost of modifying nonpiggable lines to accommodate smart pigs. (See app. IV for details on smart pig and hydrostatic testing costs.)

Conclusions

The potential for pipeline incidents can be reduced by smart pig inspections. Smart pigs can

- determine the source and location of pipe anomalies, quickly locate pipe anomalies, and enable companies to plan effective maintenance and rank repair work on the basis of the location and severity of the problem;
- locate pipe anomalies before hydrostatic pressure testing is performed so that potential line failures can be repaired before the pressure test; and
- detect a number of different types of pipeline flaws and locate girth welds, valves, and bends in the pipeline—which cannot be detected by other techniques.

However, not all pipelines can accommodate smart pigs, and smart pigs cannot detect all pipeline flaws. Nevertheless, smart pig technology can help identify potential pipeline defects and reduce pipeline incidents when used in conjunction with other inspection techniques. The cost of pigging depends on a number of variables, such as the type of pig used, diameter of pipeline, and length of pipeline pigged, among other things.

[9] J. D. Smith, P. Eng., and J. B. Lintz, P. Eng., Interprovincial Pipeline Company, "Assessment of Interactive Corrosion by High Resolution Pigging," Canadian Petroleum Association Conference, Calgary, Alberta, Canada, May 16-17, 1990, p. 16.

Mandated Safety Provisions on the Use of Smart Pigs Have Not Been Completed

To improve the safety of pipelines transporting natural gas and liquids, in 1988 P.L. 100-561 directed the Secretary of Transportation to study and report to the Congress on the feasibility of requiring the inspection of pipeline transportation facilities with smart pigs and to issue regulations requiring that new or replacement pipeline facilities, to the extent practicable, be capable of accommodating smart pigs. Almost 4 years later, RSPA has not submitted its report to the Congress and is far from issuing the mandated regulations. As of mid-September 1992, final congressional action was pending on legislation that would, among other things, direct the Secretary to issue regulations prescribing the circumstances under which smart pig inspections of natural gas pipelines in densely populated areas would be required.

We believe that RSPA needs to promptly complete the feasibility study and issue the regulations mandated in 1988. Comments we obtained during our review indicate that smart pig inspections, in conjunction with other inspection techniques, could provide RSPA and the industry with information on pipeline conditions that is not now readily available.

RSPA Has Not Completed Legislative Requirements

In line with NTSB's recommendations, the Congress mandated almost 4 years ago that the Secretary of Transportation take certain actions aimed at improving the safety of pipelines transporting natural gas. However, RSPA has not completed the legislative requirements. The mandated study on the feasibility of requiring the use of smart pigs is over 2 years late and RSPA is still in the early stages of developing the mandated regulations requiring that new or replacement pipeline facilities be capable of accommodating smart pigs. RSPA officials cited resource shortages and the need to give greater attention to other responsibilities as the primary reasons for the delays.

NTSB Made Recommendations on Smart Pigs

In 1987 a NTSB report recommended that RSPA require operators of natural gas and liquid petroleum transmission pipelines to (1) construct new pipelines to facilitate the use of smart pigs and (2) require operators to incorporate smart pig facilities when repairing or modifying existing systems. These recommendations were subsequently incorporated into the Pipeline Safety Reauthorization Act of 1988 (P.L. 100-561, approved Oct. 31, 1988). In discussing the NTSB report, an NTSB official told us that federal regulations on smart pig inspection are needed. This official believed that, if developed and used by pipeline operators, such regulations would reduce the number of pipeline incidents.

Requirements in the Pipeline Safety Reauthorization Act of 1988 Not Completed

The Pipeline Safety Reauthorization Act of 1988 required the Secretary of Transportation to study the feasibility of requiring the inspection of transmission facilities with smart pigs at periodic intervals. It required that the Secretary, not later than 18 months after the date of enactment, submit a report to the Congress detailing the Secretary's findings, together with any recommendations for appropriate legislation. This report was due to the Congress by May 1990. A RSPA official told us that RSPA prepared the study and, in November 1991, forwarded a draft to the Office of Management and Budget (OMB) for review and approval. According to this official, the study contains RSPA's proposals to develop guidelines on the use and frequency of smart pig inspections. This official informed us that RSPA received OMB's comments in March 1992 and that the study was undergoing further review and coordination within DOT as of September 1992. He added that the report would have to go back to OMB for review but that he did not know when that would be. Thus, the report is already over 2 years late. We asked for a copy of this study, but RSPA did not provide it, stating that the draft had not been cleared for release.

The legislation also required that the Secretary establish, by regulation, minimum federal safety standards requiring that new or replacement pipeline facilities, to the extent practicable, be capable of accommodating smart pigs. It did not establish a date for completing this action. A RSPA official informed us that a notice of proposed rulemaking on the minimum safety standards was undergoing review and coordination within DOT and OMB as of September 1992. However, he could not provide an estimated date for completing the review and coordination. After approval, the notice will be published in the Federal Register to solicit public comments. RSPA will then consider the comments and other information it has gathered, and develop the final rule. Thus, almost 4 years after the legislation was passed, RSPA is still in the early stages of this rulemaking.

Pending Legislation Authorizes Inspections by Smart Pigs

As of mid-September 1992, final action by the Congress was pending on two bills (H.R. 1489 and S. 1583) relating to pipeline safety. The Pipeline Safety Act of 1992 (H.R 1489) would increase the use of smart pig inspections of pipelines. This bill would, among other things, amend section 3(g) of the Natural Gas Pipeline Safety Act of 1968 (49 U.S.C. app. 1672(g)) and section 203 of the Hazardous Liquid Pipeline Safety Act of 1979 (49 U.S.C. app. 2002) to direct the Secretary of Transportation to issue regulations, within 3 years of enactment, requiring the periodic inspection of natural gas pipelines in high-density population areas by the pipeline operator. The regulations shall prescribe the circumstances, if any, under which such inspections shall be conducted with a smart pig. The bill also contains similar requirements for the inspection of hazardous liquid pipelines in environmentally sensitive and high-density population areas.

Comments on Federal Regulation of Smart Pig Pipeline Inspection

Despite congressional interest in the increased use of the inspection of pipeline transmission facilities with smart pigs and the benefits of using smart pigs to identify internal and external pipeline corrosion, there are no federal regulations on the use and frequency of smart pig inspections. During our review, we found information that would support initiating the rulemaking process for the regulations required by the proposed legislation. The rulemaking process could determine how smart pig technology can best be used to ensure pipeline integrity and safety and what issues need to be addressed before the regulations are finalized.

Our questionnaire found that although 12 companies had inspected pipelines with smart pigs, only 1 of them had used smart pigs either regularly or frequently. We believe that one of the reasons companies are not using smart pigs periodically is that no federal regulations require them to do so. (As discussed in ch. 2, there are also operational limitations for not using smart pigs, such as older pipelines with sharp bends and pipeline valves that obstruct the passage of smart pigs). Companies' use of smart pigs to inspect pipelines for corrosion is voluntary.

Comments on our questionnaire also indicated that some companies are inspecting their lines with various types of smart pigs in an effort to learn more about the pigs's capabilities and how these inspection devices can best meet their operational situations and needs. Other companies that had not used smart pigs, or had used them in limited ways, also told us that they had talked with vendors and with other companies to get more information.

In addition, our review of the activities and views of RSPA, state government pipeline inspection offices, pipeline company officials, and a professional engineering society shows that there is considerable interest in guidelines and/or requirements for smart pig inspections of natural gas pipelines. Moreover, the Canadian Standards Association has established internal inspection standards for smart pigging, which the Canadian government is considering adopting as regulations by the end of June 1993.

RSPA's Views on and Uses of Smart Pig Inspections

To help ensure the safety of pipelines, RSPA has regulations requiring external pipe coatings, cathodic protection, and hydrostatic testing,[1] but it has not issued any regulations on how, or how often, natural gas pipeline companies should use smart pigs to inspect their piggable lines. A RSPA professional engineer and the Chief of a RSPA Regional Pipeline Safety Office told us that pigging regulations, if implemented, would improve the knowledge of the condition of aging pipelines.

RSPA has recognized the capabilities of smart pig inspections to verify the integrity of pipelines. In a January 1986 study,[2] RSPA concluded that smart pig inspection is one of the practical testing/inspection methods available today, along with hydrostatic pressure testing and corrosion control monitoring, to evaluate the pipe wall safety condition of operating pipelines. The study also concluded that RSPA should continue to use the results of pressure testing and pig inspections in deciding several enforcement cases against pipeline companies involving the integrity of their pipelines.

According to RSPA testimony on its fiscal year 1990 appropriations, RSPA has enforcement authority to require companies to use smart pig inspection when safety factors warrant such use. In the last 6 years, RSPA has served hazardous facility and consent orders to natural gas and hazardous liquid pipeline companies following incidents in their lines. RSPA required the companies to use smart pig inspections to verify the integrity of the pipelines. The following are examples of such cases:

- In June 1986, following a line failure, a natural gas transmission pipeline company and OPS signed an agreement under a DOT consent order that required the company to submit (1) a plan and schedule of smart pig inspection of the lines to reveal loss of pipe wall thickness due to corrosion and (2) a schedule of pig inspection evaluations.
- On April 8, 1991, following a line failure, OPS issued a consent order and notice of proposed amendments to a hazardous liquid pipeline company in which OPS reserved the right to require the company to use a smart pig to inspect its line.

[1]Federal safety regulations on external pipe coatings, cathodic protection, and hydrostatic pressure testing were established in November 1970. Before that, the gas pipeline industry relied on the American Society of Mechanical Engineers Guidelines for the design, construction, and maintenance of natural gas pipelines. Federal pipeline safety regulations also incorporate, by reference, standards set by the various professional engineering institutes and trade associations, such as the American Gas Association, American National Standards Institute, Inc., American Compressed Gas Association, Inc., American Society of Testing Materials, Inc., and American Welding Society.

[2]Pipeline Safety Testing/Inspection Methods Study, Department of Transportation, Jan. 1986, p. 48.

- On July 5, 1991, following a pipeline leak, OPS issued a hazardous facility order to a hazardous liquid pipeline company ordering the company to take several corrective actions. One of the required actions was to use a smart pig to further verify pipeline integrity.

A RSPA official told us that, at the onset of an enforcement case, pipeline companies often present smart pig inspection results as a factor to be considered by RSPA in evaluating pipeline integrity.

State Pipeline Inspection Officials' Views

We interviewed officials of selected state pipeline inspection offices, some of which act as interstate agents for RSPA and others of which do not. The officials told us that federal regulations on the use and frequency of smart pigging would improve the knowledge of the condition and integrity of the pipelines. One official pointed out that a transmission pipeline company's previous safety record provides no assurance that lines will not eventually rupture. He said that an interstate natural gas pipeline company that had no reportable gas leaks in 30 years before 1985 experienced three ruptures over a 10-month period in 1986.

Pipeline Company Officials' Views

Officials of interstate pipeline companies told us that when federal regulations on the use and frequency of smart pigging are available, they will comply with the regulations, and that the regulations will help improve their knowledge of the condition and integrity of the pipelines. Company officials stated that they already follow a number of engineering and trade association standards relating to pipeline safety (see footnote 1). Company officials added that because the industry is vitally interested in pipeline safety, new and replacement lines are being made piggable. Among these companies were two that had never used smart pigs in their piggable lines. One of the two companies' lines are 100 percent piggable. One company official stated that the regulations would provide for a "methodical" use of smart pig technology.

Industry Standards and Guidelines for Smart Pig Inspection

During our review, we learned of three cases in which pipeline operators had established standards or guidelines for smart pig inspection. As of 1983 British Gas, formerly a British government entity, had established comprehensive engineering standards for smart pig inspection of its high pressure gas transmission lines.[3] Our review showed that these standards,

[3]British Gas Engineering Standard, BGC/PS/OLI1, Code of Practice for Carrying Out Online Inspection of Gas Transmission Systems, British Gas, PLC (London: May 1983).

which cover the use and frequency of smart pig inspection, are primarily based on quantitative analysis.[4] A senior corrosion control engineer of an interstate natural gas transmission pipeline company told us that the company had guidelines on the use of smart pigs. According to the engineer, the guidelines are based on the history of previous pipeline problems, and especially those pipelines going through environmentally sensitive and densely populated areas. Also, an interstate hazardous liquid pipeline company had established guidelines for pipeline pigging based on quantitative analysis.

National Association of Corrosion Engineers Guidelines

The National Association of Corrosion Engineers (NACE) an engineering society founded in 1943, develops standards, conducts research, sponsors training courses, and develops and administers programs for testing and certifying the qualifications of persons to perform the industry's corrosion prevention practices at both the technician and professional engineer levels. The chairman of NACE's Instrumented Inspection Devices Committee told us that his committee is developing guidelines on the use of pigs and the frequency of pig inspection. He said that a draft of the guidelines is expected in 1994.

Canadian Government's Views

The Canadian Standards Association (CSA)[5] is responsible for developing and issuing standards for various engineering, environmental, housing, health, construction, and safety fields. These standards become regulations when adopted by the government of Canada. We learned that CSA established internal pipeline inspection standards for smart pigging for hazardous liquid pipelines in 1990 and for natural gas pipelines in 1992. Officials of the Canadian National Energy Board, concerned with the integrity and safety of pipelines, told us that they are in the process of adopting the CSA standards by the end of June 1993 to make them enforceable as regulations on smart pig inspections.

Conclusions

Almost 4 years after the Congress mandated that a study on the feasibility of requiring the inspection of pipelines with smart pigs be prepared and submitted to the Congress and that minimum federal safety standards be

[4]In quantitative analysis, the probability of failure, consequences of failure, performance of cathodic protection, external coatings, ground movement, and age and construction standards of the pipeline are considered in order to arrive at priority numbers. The higher the priority numbers, the more frequent is the inspection interval.

[5]CSA is a not-for-profit, nonstatutory, volunteer membership association engaged in standards development and certification activities.

established requiring that new or replacement pipelines, to the extent practicable, be capable of accommodating smart pigs, RSPA has not completed either action. Given the potential for smart pigs, in conjunction with other inspection techniques, to determine and maintain the structural integrity and safety of aging natural gas pipelines and to improve the baseline knowledge of pipeline conditions, we believe RSPA should complete the mandated study and regulations.

Recommendations to the Secretary of Transportation

GAO recommends that the Secretary of Transportation act to expeditiously (1) provide the Congress with the final report from the smart pig feasibility study mandated by Public Law 100-561, or notify the Congress when it will be available, and (2) issue the regulations mandated by Public Law 100-561.

In carrying out the above actions, DOT and RSPA should determine how smart pig technology can effectively be used in natural gas transmission pipelines, especially those in densely populated areas. They should consider the capabilities, limitations, and costs of smart pigs and other information in this report as it relates to the role that smart pig inspections should play in DOT's overall strategy for ensuring pipeline integrity and safety.

Uses and Limitations of External Corrosion Control, Visual Inspection of Pipelines, and Hydrostatic Pressure Testing

External Corrosion Control

There are two methods of controlling external corrosion of pipelines—protective coatings and cathodic protection[1]—both of which have limitations. External pipeline coatings are made of coal tar or asphalt enamel (often used in the past) or of epoxy. All coatings deteriorate over time because they are subject to (1) operational stresses and heat buildup in lines downstream from pumping stations and (2) moisture in the soil surrounding the buried pipelines. As the coatings deteriorate, their operational strength declines and they no longer serve the intended purpose.

Cathodic protection operates by passing direct current continuously from electrodes, which are installed in the electrolyte (soil or water), to the pipeline to be protected. Corrosion is arrested when the current is of sufficient magnitude and is properly distributed. To determine the effectiveness of cathodic protection, close interval potential surveys are used. Such surveys involve measuring the voltage between the buried pipeline and its environment through a metallic electrode. These surveys provide a general idea of the extent to which corrosion has progressed and the location of "hot spots" where the corrosion is most severe. However, pipelines are sometimes subject to a "shielding effect"—an obstruction that prevents or hinders the desired flow of electric current into a cathodically protected pipeline. Such an obstruction could be casings, areas of rock adjacent to a segment of pipeline, or disbonded pipe coatings. The shielding effect sometimes leads to erroneous confirmations that the cathodic protection is effective. The Chief Engineer of the Kentucky Public Service Commission's Gas Pipeline Safety Office told us that, because of the shielding effect, cathodic protection is not totally reliable when casings are present and where lines are laid on rocky beds.

Visual Inspection of Pipelines

Visual inspection of pipelines suspected of corrosion involves excavating the pipe, inspecting the condition of the external coatings, and testing for internal corrosion. To detect internal pipe corrosion during visual inspection, a hand-held ultrasonic instrument is used. If the corrosion found is severe, that portion of the line is provided with a pipe sleeve (two halves of a pipe) welded to the existing pipe section as well as new coatings and cathodic protection.

[1]—Cathodic protection is an electrical method of preventing oxygen and moisture from reacting with steel pipe buried in soil.

A limitation of visual inspection is that only the excavated pipe segment is inspected. One consultant in ultrasonic testing told us that such testing is suitable for pipeline segments of not more than 200 feet.

Hydrostatic Pressure Testing

Hydrostatic testing identifies significant pipeline defects by causing them to fail during testing at pressure equal to 125 percent or more of the pipeline's maximum operating pressure. Any defects that fail during the test are repaired before hydrostatic testing can be resumed. However, hydrostatic testing has several limitations. One is that such testing provides only interim confidence in pipeline integrity in a case in which continuing active corrosion may increase the size and number of defects. In addition, such testing provides no information about the extent or severity of remaining corrosion damage. Furthermore, it removes the pipeline from service until testing and needed repairs are made. An official of an interstate natural gas pipeline company told us that because hydrostatic testing requires round-the-clock work for 7 days, the company tests only about 10 miles of pipeline at a time. An official of another interstate natural gas pipeline company said that his company has shut down lines for as long as 3 weeks during hydrostatic pressure testing.

In some cases, companies have loops to bypass the shut-down line so that transportation of natural gas can continue. Additionally, companies prefer to perform hydrostatic tests in the low peak season so as not to disrupt the supply of natural gas to customers. Officials of some interstate natural gas transmission companies expressed concern that hydrostatic testing leaves the lines overstressed because such tests can push insignificant pipeline flaws to the critical or near-critical limit of failure. They said that, in some cases, pipeline failures have occurred in lines following hydrostatic pressure testing.

Hydrostatic testing is also required when a transmission company wishes to increase the volume of natural gas transported. Increasing the volume of gas transported requires boosting the operating line pressure. The Department of Transportation's (DOT) Research and Special Programs Administration (RSPA) can order a line to be shut down or have the line pressure reduced to a safe operating pressure if it finds that the company boosted the line pressure in a manner not in accordance with regulations on uprating pressure.

RSPA has the authority, under enforcement orders, to require pipeline operators to perform hydrostatic tests of their lines if it believes such tests to be necessary. A RSPA official told us, for example, that an interstate hazardous liquid pipeline company had consented (consent order dated Oct. 9, 1987) to hydrostatically test 5,000 miles of its lines over a 6-year period because of a history of longitudinal seam-related failures in its low frequency electric-resistance-welded pipelines. According to a 1989 RSPA study,[2] lack of proper fusion of seam welds was a problem in the low frequency electric resistance welding method, which was prevalent in the United States before the 1970s.

[2]Electric Resistance Weld Pipe Failures on Hazardous Liquid and Gas Transmission Pipelines, Technical Report-OPS 89-1; Office of Pipeline Safety, Department of Transportation, Aug. 1989.

Types of Technologies, Commercial Availability, and Sizes of Smart Pigs

Types of Smart Pig Technologies

There are two types of smart pig technologies—magnetic-flux leakage measuring and ultrasonic. Magnetic-flux pigs are used for inspecting hazardous liquid and natural gas pipelines. Ultrasonic pigs are used only for inspecting liquid pipelines, because they require a liquid medium such as methanol, glycol, or water to operate. Simply stated, ultrasonic pigs can be used for inspecting a natural gas pipeline provided it is emptied first and refilled with a liquid medium. Alternatively, the ultrasonic pig in a liquid medium is placed in the pipeline preceded and followed by a sealing pig to seal the natural gas from the liquid medium.

A magnetic-flux pig carries powerful permanent magnets—which are coupled to the pipe wall by high-density brushes—that induce a magnetic field into the wall being inspected. When an anomaly such as metal loss has occurred in the inside or outside surface of the pipe wall, a change takes place in the magnetic field. Rows of sensors, which cover the complete circumference of the pipe wall, are set between the poles of the magnets. These sensors detect changes in magnetic flux in the magnetic field as the pig moves through the pipeline. Signals created by anomalies in the pipe wall are stored on a magnetic tape within the pig. The information on the tape is then converted to a photographic log, which is used for visual inspection.[1] In areas where no anomalies exist, a leakage field does not occur and nothing is recorded.

An ultrasonic pig carries ultrasonic transducers. Ultrasonic waves transmitted to the inner and outer pipeline walls are reflected back to the transducers, which measure precisely and directly the pipe wall thickness, including areas where corrosion has caused the wall to thin.

Commercial Availability of Smart Pigs

Tuboscope Linalog, Inc., a U.S. company, developed the first magnetic-flux smart pig for commercial pipeline inspection in 1965. Vetco, another U.S. company, has marketed magnetic-flux smart pigs for pipeline inspection since 1972. (Vetco also markets pigs that measure deformation and slope; these have been available since 1988.)

Pipetronix of Germany manufactures magnetic-flux smart pigs, which have been available for pipeline inspection since 1975. In 1986 Pipetronix developed an ultrasonic smart pig. In 1991 Pipetronix's high-resolution magnetic-flux smart pig became available.

[1] Data on the magnetic tape are reproduced on paper and the result is called an inspection log. Each 8-inch-wide and 200-foot-long roll contains 6 miles of pig inspection data.

British Gas's magnetic-flux smart pigs have been in commercial use in Great Britain, Europe, and Middle Eastern countries since 1975. In the United States, British Gas pigs have been used since 1987.

Rosen of Germany produces magnetic-flux smart pigs that have been in commercial use in European and Middle Eastern countries since 1988. In the United States, Rosen pigs have been used since 1989. (Rosen has also marketed electronic-geometry smart pigs for commercial use since 1982. These pigs detect and measure variation in the geometry of the pipelines.

NKK of Japan manufactures ultrasonic smart pigs that have been in commercial use since 1987. In the United States, NKK pigs have been used since 1988.

T.D. Williamson, a U.S. company, has produced ultrasonic pigs since 1988.

Sizes of Smart Pigs

Table II.1 shows the sizes in which smart pigs are available, according to smart pig vendors.

Table II.1: Sizes of Smart Pigs Available

Manufacturer and type of smart pig	Pipeline diameter for which smart pig is available
Vetco deformation-slope pig	6-18 inches in increments of 2 inches; 30-48 inches in increments of 2 inches
Vetco magnetic-flux pig	4-48 inches in increments of 2 inches
Tuboscope magnetic-flux pig	4-48 inches in increments of 2 inches
Pipetronix magnetic-flux pig	12-48 inches in increments of 2 inches
Pipetronix Magnescan high resolution magnetic-flux pig	30-48 inches in increments of 2 inches
Pipetronix ultrasonic pig	6-48 inches in increments of 2 inches
British Gas second generation magnetic-flux pig	8-48 inches in increments of 2 inches
Rosen high-resolution magnetic- flux pig	6-48 inches in increments of 2 inches
Rosen electronic-geometry pig	6-48 inches in increments of 2 inches
NKK ultrasonic pig	16-48 inches in increments of 2 inches
T.D. Williamson ultrasonic pig	8-36 inches in increments of 2 inches
T.D. Williamson caliper (deformation) pig	8-48 inches in increments of 2 inches (44-inch and 46-inch sizes are not available)

Natural Gas Pipeline Companies That Completed GAO'S Survey of Application and Use of Smart Pig Technology

U.S. Companies

Arkla Pipeline Company
American Pipeline Company
Bridgeline Gas Distribution Company
CNG Transmission Corporation
Columbia Gas Transmission
Enron Gas Pipeline Corporation
K.N. Energy, Inc.
Panhandle Eastern Corporation
Northern Border Pipeline Company
Northwest Pipeline Corporation
Pacific Gas Transmission Company
Southern Natural Gas Company
Transcontinental Gas Pipe Line Corporation
Valero Transmission, L.P.
Willston Basin Interstate Pipeline Company

Canadian Companies

Nova Corporation (Alberta Gas Transmission Division)
TransCanada Pipelines
Westcoast Energy, Inc.

Various Results of GAO'S Smart Pig Survey

Classifications and Choices of Smart Pigs

Smart pig manufacturers classify their magnetic-flux instruments as either first-generation (low-resolution) or second-generation (high-resolution) smart pigs. In general, second-generation, or high-resolution, pigs have state-of-the art technology and more advanced capabilities for detecting pipeline flaws. We reviewed manufacturers' classifications of their instruments' technology and asked the natural gas pipeline companies which types of smart pigs they had used and how they classified them. We found that the responding companies had used five different pigs, but that they did not always agree with the manufacturers' classifications of the pigs.

Manufacturers' Classifications

The British Gas magnetic-flux smart pig is marketed as a second-generation pig. Germany's (Magnescan HR) Pipetronix magnetic-flux pig is marketed as a high-resolution pig. Both of these manufacturers use digital computer technology and data processing to provide qualitative[1] and quantitative[2] data about pipeline features to be collected and analyzed. According to these manufacturers, individual pipeline defects can be examined more closely on a computer screen using color mapping and three-dimensional contour drawings to accurately measure the defects' length, depth, and physical characteristics. Rosen of Germany also markets its magnetic-flux smart pigs as high-resolution pigs. Digital computerized inspection data are available for Rosen pigs of 20 inches in diameter or more.

Vetco, a U.S. company, does not market its smart pig as either second-generation or high-resolution technology. However, it is developing a high-resolution magnetic-flux pig with more sensors to cover the pipeline's inner surface. Vetco provides digital computer technology and data processing for pipeline inspection analysis. Tuboscope Linalog, the first American manufacturer to commercialize the magnetic-flux smart pig, identifies its smart pig technology as first generation. Tuboscope can provide pipeline corrosion data in three-dimensional form comparable to that provided by the British Gas pig if the customer is willing to pay the added cost.

[1]Qualitative data describe anomalies that are detected by the pig but cannot be quantified in terms of length and depth.

[2]Quantitative data provide information about pipe flaws in three-dimensional form (length, breadth, and depth).

Companies' Use of Magnetic-Flux Smart Pigs

We asked the companies which types of magnetic-flux smart pigs they had used. We received responses from 12 companies, some of which had used more than one type. The responses are shown in table IV.1.

Table IV.1: Twelve Companies' Use of Magnetic-Flux Smart Pigs, by Country of Manufacture

Country of manufacture	Number of companies
United States (Vetco, Tuboscope)	10
Great Britain (British Gas)	1
Germany (Rosen)	1
Germany (Pipetronix)	4

While 10 of the 12 companies had used U.S.-manufactured pigs, four companies had used pigs manufactured by more than one country. Two of the 12 had used U.S-manufactured and German Pipetronix pigs. One of the 12 had used U.S.-manufactured and British Gas pigs.

We asked the companies that had used magnetic-flux pigs to tell us how many years they had been using pigs. Their responses varied from a company that had used a pig one time only in a short section of pipeline (to test the pig) to a company that had been using pigs for 25 years.

Pipeline Companies' Opinions on Classification of Smart Pig Technologies

We asked the companies that had used magnetic-flux smart pigs to compare the levels of technology of the various pigs. Their opinions were mixed. All agreed on first-generation pig classification, but they differed as to whether pigs marketed as second-generation or high-resolution were superior to pigs marketed as first-generation technology.

British Gas versus German Rosen Magnetic-Flux Smart Pigs—Although no gas pipeline company had used both the British Gas and the German Rosen pigs, 6 of 12 companies categorized both pigs as second-generation pig technology. Their opinions on the classification of the pigs were based primarily on the two pig manufacturers' technical literature and on discussions with others in the pipeline industry. On the other hand, one company said that both the British Gas and the Rosen pig were first-generation technology. Two other companies also said that Rosen pig technology is first generation. One company based its opinion on actual use of the Rosen pig and the other on discussions with others in the pipeline industry.

British Gas versus Pipetronix Magnetic-Flux Technology—One company that had used a British Gas pig believed that, based on technical literature and its conversations with other pipeline companies, the British Gas technology is superior to that of Pipetronix.

U.S.-Manufactured Magnetic-Flux Technology—All 12 companies considered the U.S.-manufactured Vetco and Tuboscope pigs to be first-generation smart pigs. They commented that these pigs have been in use for 25 years and that basic magnetic-flux leakage measuring technology has not changed except for some fine tuning. One company said that the Vetco smart pig is catching up with the technology of the British Gas and German Rosen pigs.

Companies' Reasons for Using Various Types of Smart Pigs

Most companies that responded to our survey used U.S.-manufactured, first-generation magnetic-flux smart pigs for reasons of cost, availability, and operational requirements. One company said that the information obtained from first-generation pigs was sufficiently accurate to satisfy inspection standards at the most competitive cost. Another commented that newer models of first-generation pigs provide generally reliable information on length, location, and depth of corrosion. Other companies lauded the first-generation pigs' reliability, the easy availability of inspection data from U.S. pig vendors, and employees' familiarity with interpreting these inspection data. Another noted simply that U.S. pigs are readily available to the industry.

One company used either first-generation/low-resolution pigs or second-generation/high-resolution pigs to assess the risk associated with an unplanned service interruption of a specific pipeline. In general, it selected low-resolution pigs for pipelines with a low service interruption probability and moderate consequences of failure. In cases in which consequences of failure were rated very high, a high-resolution pig might be used even though the probability of service interruption is estimated to be moderate or low.

Four of the 12 companies used a high-resolution Pipetronix magnetic-flux smart pig for similar reasons—cost, availability and operational requirements. One company said that the fact that the Pipetronix was shorter in length than other pigs was a positive factor in modifying pig launchers and receivers in its pipelines. Another company cited lower competitive bids by Pipetronix and the ready availability of its pigs.

Pipeline Flaws Identified by Smart Pigs

As discussed in chapter 2, we asked the companies that have used pigs to list flaws identified by magnetic-flux smart pigs. The responses are shown in table IV.2.

Table IV.2: Number of Natural Gas Pipeline Companies That Identified Pipeline Flaws Using Smart Pigs

	Number of Companies Using Magnetic-flux Smart Pigs			
Pipeline flaws	**U.S. Vetco, Tuboscope**	**British Gas**	**German Rosen**	**German Pipetronix**
Corrosion pitting	10	1	1	5
Mechanical damage	7	0	1	1
Axial gouges	5	0	1	0
Circumferential gouges	6	0	1	0
Dents	6	0	1	1
Mill defects	8	1	1	0
Wrinkle bends	5	0	1	0
Hard spots	1	0	0	0
Hydrogen blisters	0	0	0	0
Circumferential cracks	0	1	0	0
Longitudinal cracks	0	0	0	0
Laminations	5	0	0	0
Detects and locates girth welds, valves, tees, bends	6	1	0	2
Bacterial condition	1	0	0	0
External coating integrity	0	0	0	0
External coating disbond location	0	0	0	0
Internal coating integrity	0	0	0	0
Internal coating disbond location	0	0	0	0

Smart Pigs: Advantages and Disadvantages

As discussed in chapter 2, we asked the companies that have used smart pigs to comment on the advantages and disadvantages of using smart pigs. The responses are shown in table IV.3.

Table IV.3: Advantages and Disadvantages of Using Smart Pigs

	Number of companies		
		Experienced using	
Advantages	Not experienced	First generation	Second generation
Establish existing pipeline conditions	0	11	4
Determine source and location of internal/external problem	0	12	4
Prioritize repair work based on location and severity of the problem	1	9	4
Minimize costly product loss	4	4	1
Minimize pipeline system downtime	4	5	1
Evaluate use value before sale or purchase of pipeline system	4	3	0
Establish data to confirm performance of cathodic protection of pipeline	4	4	0
Evaluate maintenance procedures	6	1	1
Plan effective maintenance	2	6	4
Observe recurring conditions on future pigging inspections	5	3	2
Regular use of pigs provides an opportunity to compare changes in the pipeline system	7	0	0
Quicker location of anomalies	1	10	2
Cost advantage over hydrostatic testing	4	5	3
Measurable increase in line and efficiency	7	0	1
Measurable increase in throughput	7	0	0
Monitor the effectiveness of corrosion-inhibition program	4	3	0
Meet regulatory agencies' requirements that the pipeline is being operated and maintained in a safe manner	5	3	2
Disadvantages			
Time involved in mobilization/ demobilization	3	4	2
Inability to detect corrosion at bends	4	1	0
Cost	1	5	3

Companies' Observations on Smart Pigs' Capabilities

We asked the companies to respond to specific questions about the capabilities of the smart pigs they had used. Most of the questions dealt with first-generation pigs because they are the most widely used. The companies' responses were divided on the pigs' abilities to make quantitative and qualitative analyses of pipeline features. Seven companies responded positively on the pigs' ability to discriminate among structural features such as pipe valves, sleeves, and tees in the pipeline, and eight responded negatively on the ability to detect metal loss in circumferential welds and to identify three-dimensional defects.

Capabilities of First-Generation Pigs

Provide Quantitative Analyses of Pipelines—Companies were split down the middle on this question: Six said that first-generation pigs can provide the quantitative extent of pipeline features and six said that they cannot.

Provide Qualitative Analyses of Pipelines—Companies were slightly more positive in their response to the question of providing qualitative analysis: Seven said that smart pigs can provide qualitative analyses and five said that they cannot.

Discriminate Among Structural Features of Pipelines—Seven companies said that first-generation magnetic-flux pigs can discriminate between significant and insignificant structural features of the pipeline; five said that they cannot. One company noted that the pigs can clearly identify such features as pipeline valves and sleeves. Several companies commented that accurate discrimination depended on the skill and experience of those who analyze the pig inspection data. According to two companies, however, even experienced pig inspection log interpreters can be fooled by readings on some types of defects. According to another company, if "significant" structural features are defined as corrosion damage that would cause the pipe segment to fail under hydrostatic test pressure, the existing first-generation tools are not capable of providing data required for this kind of discrimination, such as the depth and length of the corrosion damage.

Detect Metal Loss in Circumferential Welds—Pipes are manufactured in certain lengths, which are then welded together at the ends to make the continuous line. These welds are called circumferential, or girth, welds. Only two companies said that first-generation magnetic-flux smart pigs can detect metal loss in girth welds; eight said that they cannot. Of the two companies that answered positively, one said that first-generation pigs can find corrosion next to and in girth welds, but the other company giving a positive response said that the pigs could not detect all metal loss in such welds. One company said that a proper weld will have a "bead" (area of raised fused metal) that will cause a moving pig to "jump" as it passes and miss any metal loss. Other companies agreed that the signals from the pigs' sensors are distorted in the immediate weld area; one said that pigs cannot detect anomalies for 6 inches on either side of a weld.

Detect Three-dimensional Defects—Corrosion can be measured in terms of the length and width of the corroded area and how deeply it penetrates the pipe wall. Three companies said that first-generation magnetic-flux smart pigs can measure defects in all three dimensions, but seven said that they cannot. One company that responded negatively said that pigs do not have enough sensors to measure all three dimensions accurately. Another said that first-generation pigs give only an indication of the defects' dimensions.

Comparison of First- and Second-Generation Pig Capabilities

As noted earlier, companies were divided as to whether the smart pigs that manufacturers claimed to be second-generation or high-resolution were technically superior to first-generation pigs. A Canadian company commented that the British Gas pig is the only high-resolution pig on the market to measure the depth and length of detected corrosion damage with the accuracy that meets the company's requirements and allows it to perform engineering critical assessment of the damage. Two companies that had not used either the British Gas or Rosen pigs said that these pigs have better electronics and the ability to detect smaller flaws than first-generation pigs.

Technology Improvements Suggested for Smart Pigs

We asked the respondents to comment on what elements of data analysis and interpretation should be further developed for magnetic-flux pig technology. The companies told us that smart pigs could be improved by developing their ability to detect defects that they cannot now detect, such as metal loss in weld zones and disbonded coatings, as well as to more accurately measure the depth and length of corrosion. The companies also would like to see improvements in data interpretation, such as more readable inspection logs, computerized analysis of the data on personal computers at the field level, and correlation of pig inspection logs with actual measurement of pipe anomalies obtained after excavation of the line.

Smart Pig and Hydrostatic Testing Costs

Because so many variables are associated with the costs of testing pipelines with both smart pigs and hydrostatic pressure, cost estimates from our survey and from other sources varied widely. However, available studies, including cost estimates made by RSPA, indicate that hydrostatic pressure testing is more expensive than smart pigging. We stated earlier that neither technique can be substituted for the other because each provides information unique within its own scope. The higher cost of hydrostatic testing is the result of several factors; two of these are (1) the total interruption of natural gas throughput during the test, which reduces the operator's revenue, and (2) the costs of treating and disposing of contaminated test water after the test. Smart pigging does not require emptying the lines.

The process for hydrostatic pressure testing of liquid and natural gas pipelines is generally the same. Hydrostatic testing of pipelines is an expensive technique to establish pipeline pressure integrity because of the number of cost elements involved. These cost elements include (1) the test process, including the mobilization and demobilization of resources and equipment; (2) cleaning the line before and after the test with a cleaning pig; (3) acquisition, transportation, and disposal of test water; (4) state and federal environmental permit requirements for acquiring, transporting, and discharging tested water and laboratory analysis of discharged water; (5) treatment of discharged water;[3] (6) revenue lost from lost throughput capacity while the test is being done; (7) revenue lost while the storage tanks for liquids that normally hold the transported commodity are being used to hold test water;[4] and (8) repair of pipe blowouts that may occur during the testing. A 1986 study reported that a leak or rupture could add

[3]California requires hazardous waste water to be treated before reinjection into permitted deep wells or other forms of permitted disposal. For hydrostatic test water from natural gas or hazardous liquid pipelines, Kentucky's Elimination System Branch in the Division of Waters Pollutant Discharge requires the applicant to submit a notice of intent to discharge, which would include the following information: length, age, and type of pipeline to be tested; location; discharge date; source of water used in the testing; volume of water to be used; duration; and receiving stream for the discharged water. The division would then issue an approval letter indicating the conditions under which the applicant would be allowed to conduct the hydrostatic testing. If an individual permit is required for testing the hazardous liquid pipelines, the permit fee can vary from $1,000 to $2,100. The applicant would need to provide information on the pollutants that may be present in the discharged tested water. The permit specifies appropriate effluent limitations for the discharge type and the location of the receiving stream.

[4]Practices vary with the pipeline operators. Those who do not store water transport it to and from the test segment by pipeline batching or procure it locally and either dispose of it locally or transport it to other places for treatment.

up to $10,000 or more per event to the testing cost.[5] Cost estimates for hydrostatic testing liquid and natural gas pipelines are discussed below.

An American Petroleum Institute study estimated the cost of subjecting all interstate pipelines to a hydrostatic test once during a 3-year period as $5,300 per mile.[6] The study did not show the assumptions made or the cost elements considered. According to a Transportation Research Board (TRB) report,[7] RSPA reported that hydrostatic testing usually costs between $2,890 and $6,642 per mile of liquid lines and between $6,200 and $9,600 per mile of natural gas lines. The TRB report did not show the assumptions RSPA made or the cost elements RSPA considered in calculating the cost, although it said that the cost of throughput of natural gas lost during testing was not included.

A proposed RSPA rulemaking document showed that hydrostatic pressure testing cost $4,656 per mile of pipeline with an average pipe diameter of 20 inches.[8] According to the document, this cost was developed from industry sources.[9] An official of the industry source that provided the cost figure to RSPA told us that the $4,656 did not include the cost of transporting, treating, and disposing of the tested water. According to the industry official, transporting and disposing of tested water containing more than 0.5 ppm (parts per million) of benzene—classified as a hazardous waste by the Environmental Protection Agency (EPA)—cost an additional $1.5 million for 190 miles of 26-inch-diameter pipeline, or $7,894 per mile. He added that revenue lost during the 3 weeks of testing was $1,600 per mile. Thus, the cost of testing per mile totaled $14,150 ($4,656[10] + $7,894 + $1,600), or about $2.70 per foot.

[5] J.F. Kiefner, R.W. Hyatt, and R.J. Eiber, NDT [Non-Destructive Testing] Needs for Pipeline Integrity Assurance, Final Report PR-3-624 to American Gas Association, Battelle (Columbus, Ohio: Oct. 6, 1986), p. 34.

[6] Michael Rusin and Evi Savvides-Gellerson, The Safety of Interstate Liquid Pipelines: An Evaluation of Present Levels and Proposals for Change, Research Study 040, American Petroleum Institute (Washington, D.C.: July 1987), p. 53.

[7] Pipelines and Public Safety, Transportation Research Board, Special Report 219 (Washington, D.C.: 1988), p. 114.

[8] Proposed rulemaking entitled Economic Evaluation, NPRM—Hydrostatic Testing of Certain Hazardous Liquid and Carbon Dioxide Pipelines, Department of Transportation, May 13, 1991, pp. 5 and 9.

[9] Department of Transportation 1991 proposed rulemaking, p. v.

[10] Although this figure is based on an average pipeline diameter of 20 inches, we used this cost for computing the cost of testing the 26-inch-diameter line to be on the conservative side.

The industry official told us that it is highly likely that hydrocarbons—constituents of the hazardous liquids and natural gas—will always be present in the tested water of existing lines, although they may not always be present in quantities exceeding the EPA threshold. Assuming that the level of hydrocarbons in the tested water is below the EPA threshold, the cost of treatment and disposal of tested water would be reduced by two-thirds of $7,894, or $5,263 per mile. Thus, the cost of testing such lines amounts to $8,887 ($4,656 + $2,631 + $1,600) per mile, or about $1.70 per foot.

Natural gas in transmission lines contains a minute amount of oil residues emanating from the pumping stations and a component of gas production called condensate—an oily liquid. Because of minute amounts of oil residues and condensates, tested water often has to be treated in an manner acceptable to a state environmental and water quality board before the water is disposed of. A consultant in ecology and environmental engineering told us that before 1974 an amber-colored liquid called Therminol, which contained 75 percent PCB (polychlorinated biphenyl), was used in turbine compressor stations. According to an EPA official, some states regulate PCB as a hazardous substance under the Resource Conservation Recovery Act. The Therminol, along with the condensate transported in the pipeline, would coat the inside of the pipeline. Pipeline companies were able to remove the condensate, but residual PCB—an extremely stable chemical—remained in certain areas of the pipeline.

According to the same ecology and environmental engineering consultant, residual PCB is still present in natural gas pipelines, but its concentration level is decreasing. Water used for hydrostatic pressure testing that contains PCB has to be transported and treated at a Resource Conservation and Recovery Act-approved treatment storage and disposal facility. Such transportation and treatment of tested water is time-consuming and expensive. An Illinois official in charge of the state's industrial waste permit section told us that PCB concentration must be less than 0.5 to 1 parts per billion before the state would allow the treated water from a hydrostatic test to be discharged into surface water. An official with an interstate natural gas pipeline company told us that pressure testing and transportation and disposal of treated water costs the company $2 per foot of pipeline, or about $10,560 per mile. An official of another interstate natural gas pipeline company told us that this cost appeared reasonable.

The cost of hydrostatic pressure testing can further increase (1) with increasing pipe diameter; (2) when lines cross hilly terrain, because fewer pipeline lengths—usually about half a mile—can be tested at a time;[11] and (3) when water is scarce, which is the case in certain parts of the United States, especially in western Texas, Arizona, and New Mexico.

Compared with the cost estimates of $8,887 to $14,150 per mile for hydrostatically testing interstate hazardous liquid pipelines and about $10,560 per mile for such testing of interstate natural gas lines, the cost of pigging per mile of interstate pipelines experienced by the companies in our survey ranged from $650 per mile to $2,400 per mile in 1991. In other words, the cost of using hydrostatic pressure testing of natural gas transmission lines could be as much as 4.4 times higher than the cost of inspecting them with smart pigs—using the higher range of the cost of pigging.

Three foreign smart pig manufacturers provided their pigging costs for an average pipeline diameter of 24 inches and 100 miles long. The cost ranged from $1,200 to $4,000 per mile. Even then the cost of hydrostatic testing would be 2.64 times higher than the high end of the smart pigging cost range.

[11] Every 100 feet of elevation change is equal to 43 pounds per square inch gauge of hydrostatic pressure head on the lower end of the test section.

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